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ENVIRONMENTAL ASSESSMENT OF THE OAK RIDGE GASEOUS DIFFUSION PLANT SITE

December 1979

Oak Ridge Gaseous Diffusion Plant
Oak Ridge, Tennessee

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prepared for the
DEPARTMENT OF ENERGY

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1. SUMMARY

1.1 INTRODUCTION

The possibility of constructing nuclear weapons for use in World War II resulted in the decision to build the Oak Ridge Gaseous Diffusion Plant to provide the necessary large-scale separation of uranium-235 from natural uranium. Construction was started in 1943, and the first diffusion cascade facility, known as K-25, was in full operation by August 1945. After the war, the nation's nuclear energy effort continued to meet defense needs and, in addition, was directed toward the peaceful goal of providing electric power. Low-enriched uranium is expected to be the primary source of fuel for nuclear power reactors during the remainder of this century. The conventional light-water reactors require uranium enriched to a nominal uranium-235 content of 3%. Since natural uranium contains only 0.7% uranium-235, an enrichment process is needed to provide reactor fuel. Enrichment currently is provided by the gaseous diffusion process, which is carried out in three plants operated for the U.S. government. The plants are located near Piketon, Ohio; Paducah, Kentucky; and Oak Ridge, Tennessee.

At the time of this assessment, the diffusion cascades at Oak Ridge are being upgraded and uprated to provide additional enrichment capability. In addition, extensive effort is being expended on the development of alternative enrichment processes. Particular emphasis is being placed on the gas centrifuge process, with facilities now being constructed to house pilot-plant-scale operations. Operation of the Oak Ridge Gaseous Diffusion Plant (ORGDP), projected to 1984, after all uprating and improvements have been completed and the plant is operating at full capacity, is the subject of this assessment.

1.2 DESCRIPTION OF ORGDP

The ORGDP is located on a level 640-acre tract of land near the junction of Poplar Creek and the Clinch River on the 37,300-acre Oak Ridge Reservation in Roane County, Tennessee. The only thoroughfares providing access to the plant site are Blair Road from the north and Tennessee Highway 58 from the northeast and southwest.

The five largest buildings are the diffusion-process facilities — K-25, K-27, K-29, K-31, and K-33. The K-27 building is in standby condition and the K-25 building is used only as a warehouse; thus, neither is involved in the enrichment process. Other buildings house administration, data processing, laboratories, decontamination and uranium-recovery facilities, fabrication and maintenance equipment, the diffusion-cascade barrier-manufacturing plant, the nickel-plating facility, the fluorine plant, hydrogen fluoride storage area, the gas centrifuge projects, the fossil-fueled steam plant, supply stores, and various other support services. The mechanical-draft cooling towers provide a means of dissipating over 1800 MW of waste heat from the gaseous diffusion process, and the vapor plumes are visible for a distance of several miles during the cooler months of the year.

By 1984, about 2080 MWe will be supplied the ORGDP by the Tennessee Valley Authority (TVA). This is about 6.6% of TVA's total generating capacity. All transmission lines are constructed according to TVA's specifications and standards and are either 161 or 500 kV, with their respective transmission corridors 100 and 175 ft wide.

The transportation of uranium hexafluoride (UF_6) and other materials, by rail and truck, is an important part of ORGDP operations. The UF_6 shipments are primarily between ORGDP and the other government-owned diffusion plants, UF_6 production plants, and fuel-processing facilities. All shipments are regulated by both the Department of Energy and the Department of Transportation.

There are over 100 points where discharges are made to the atmosphere. However, only six different constituents are released in significant quantities: SO_2 (3.2×10^6 kg/year), NO_x (4.3×10^5 kg/year), HF (9.5×10^2 kg/year), particulates (3.8×10^2 kg/year), radioactivity [uranium and technetium-99 (6.6×10^{-4} Ci/year)], and the fluorocarbons (1.1×10^5 kg/year) used in cooling systems. The six major release points for liquid effluents are regulated by National Pollutant Discharge Elimination System (NPDES) permits. The total amount of radioactivity released from these points is about 3 Ci/year of technetium-99 and about 0.33 Ci/year of uranium (various isotopes). Information such as this is obtained from an effluent monitoring program, whereas quantitative information on the environment itself is obtained from an environmental monitoring program. Through these two programs, the effects of plant operation on the environment are well documented.

1.3 ALTERNATIVES

Several alternatives to continuing the present mode of operation (1984 time frame) of ORGDP have been considered. These include (1) shutdown or reduced operation, (2) replacement of the gaseous diffusion process with an alternative process, and (3) relocation of the present facility to another site. It was concluded that (1) ORGDP should continue to operate to fulfill contractual agreements with the private sector; (2) conversion to either the gaseous centrifuge or an advanced isotope separation technology is not economically or environmentally justifiable at this time; and (3) operation of the plant at its current site is environmentally preferable to relocating to another site.

Two alternatives for supplying the electric power requirements of ORGDP (currently supplied by TVA) are considered: (1) power supply by a government-owned, dedicated plant and (2) power supplied by a private utility. It is concluded that supply by TVA is preferable to the alternatives, both economically and environmentally.

Several alternative subsystems are under investigation; possible implementation depends on the results of ongoing technical and economic feasibility studies. These potential alternatives are (1) use of waste heat for space heating of buildings; (2) recovery of some of the uranium and technetium now discarded in liquid and solid wastes; (3) recycle of contaminated scrap metal by smelting and refining rather than continued aboveground storage; and (4) disposal of radioactively contaminated solid waste by chemical fixation of the radionuclides into a nonmobile state prior to land burial or disposal by hydrofracture.

Proposed line-item improvements, many of which are in draft form, are listed. Some of these are needed to comply with the "best available treatment economically achievable" (BATEA) criteria of the Clean Water Act and the Resource Conservation and Recovery Act (RCRA). These proposed improvements include, among others, (1) additional scrubbers for fluorine and fluoride removal from gaseous effluents, (2) new settling ponds to better control the quality of the liquid effluents, (3) collection and treatment of runoff from coal piles, (4) containment dikes for the accidental release of PCBs, and (5) oil traps in storm sewers.

1.4 EXISTING ENVIRONMENT

The ORGDP site in Roane County is in a low-population-density area; about 35% of the area is farmland, and the remaining 65% is wooded. The climate is classified as humid subtropical, and the yearly average temperature is 14.4°C (average monthly temperature varies from 5°C in the winter to 27°C in the summer). Rainfall annually averages about 150 cm. The weather is clear 30% of the time; partly cloudy, 25%; and cloudy, 45%. Inversion conditions occur about 30% of the time. Winds are primarily bimodal in nature, consisting of prevailing up-valley (SW) and down-valley (NE) flow. The peak gust recorded is 95 km/hr.

The elevation along the Clinch River (Watts Bar Reservoir) is about 226 m above mean sea level with a maximum relief of 128 m to the ridge crests. The hydrodynamics of the Clinch River–Poplar Creek system in the ORGDP area is complex because of variation in Clinch River flow (0 to 18,000 cfm) caused by regulating the flow at Melton Hill Dam to correspond to the needs for power generation and flood control. The waters are moderately hard, well buffered, and slightly alkaline. The principal cation is calcium, and the principal anions are bicarbonate and carbonate.

The major stratigraphic units underlying the site and its confining ridges are the Rome Formation, the Conasauga Group, the Knox Group, and the Chickamauga Limestone. The depth of alluvium beneath the site ranges from near 0 to 18 m. The Whiteoak Mountain Fault system runs through the southeastern corner of the site. Since there are no recorded seismic events associated with these faults, they can probably be considered inactive. It is estimated that the largest earthquake to be expected in the area within a 100-year interval is 7.3 on the Modified Mercalli scale.

A wide variety of wildlife exists in the area surrounding ORGDP. The reservation is closed to hunting, and white-tailed deer are in abundance, as are cottontail rabbits, eastern gray squirrels, opossums, woodchucks, skunks, raccoons, red fox, and other small mammals. Canada geese are the most important of the nesting waterfowl on the reservation. Quail and mourning doves are in abundance. Thirty species of fish from 10 families have been collected in the ORGDP area. Fish collected in Poplar Creek consist of about 32% game fish, 23% rough, and 45% forage; the gizzard shad is the most common species.

1.5 ENVIRONMENTAL CONSEQUENCES

Less than 0.0007 Ci of radioactivity, mostly isotopes of uranium, as particulates, is released to the atmosphere each year from ORGDP operations. Doses to the maximally exposed individual, located 4 km SW of the plant at the boundary fence, and to the total population (678,000) living within 80 km of the plant have been estimated. In both, the maximally exposed individual and the population as a whole, ingestion (exposure mode) of uranium-234 contributes most of the dose. For the maximally exposed individual, the total-body dose is 0.0037 millirem/year; the highest organ doses are to the bone (0.041 millirem/year) and the kidney (0.0019 millirem/year). The annual total population dose is 0.044 man-rem for total body; organ doses vary from 0.0017 to 0.49 man-rem. The dose to the same population from natural background is 68,000 man-rems/year. All doses are well below current NRC regulations and future EPA standards.

About 3 Ci of technetium-99 and <0.4 Ci of uranium isotopes are released annually to Poplar Creek and the Clinch River. The dose to individuals who might make maximum use (drinking, swimming, fishing) of these waters has been calculated. The estimated doses from all aquatic pathways to the total body and organs are well below 1 millirem/year and do not significantly add to the total dose of the individual. The highest dose received, 0.69 millirem/year (bone dose from Poplar Creek water usage), is only 3% of the future EPA limit (25 millirem/year to the bone).

The radioactive burial grounds could conceivably contaminate a drinking water supply (Clinch River). The staff has assessed this worst-impact possibility and concludes that for any realistic release rate, a maximally exposed individual (river water sole source of drinking water) would receive an insignificant dose (<<1 millirem/year).

Under average meteorological conditions, it is estimated that the maximum air pollutant concentrations at the ORGDP boundary resulting from nonradioactive atmospheric releases from process buildings and cooling towers in 1984 will represent 40%, 44%, and 3% of the Tennessee ambient air quality standards for HF, SO_2, and NO_x respectively.

Elevated concentrations of fluoride, cadmium, and zinc were found in reservation vegetation, and elevated fluoride concentrations were found in some animals. However, there were no symptoms of fluorosis in any of the 416 small animals examined.

Fogging and icing are increased by ORGDP operation over the amount normally experienced in the area. The occurrence of fogging along Tennessee State Highway 58, adjacent to ORGDP, is estimated to be increased by about 16% over natural fog occurrence.

Water withdrawn from the Clinch River for ORGDP use will amount to 24 Mgd in 1984. About 18 Mgd will be lost to the atmosphere as evaporation from the cooling towers; the remainder will be returned to the river. This consumption does not cause a significant impact on the river water supply.

Electric power (about 2080 MWe consumed in 1984) is supplied by the Tennessee Valley Authority. About 6.6% of TVA's generating capacity is committed for use by ORGDP. Since specific dedicated plants do not supply this power, the environmental impacts of supplying ORGDP power are considered a proportion of the total environmental impact of the operation of the TVA network of hydroelectric, coal, and nuclear generating facilities. Based on the projected mix of TVA generating facilities for 1984, the facility breakdown will be about 300 MWe hydroelectric, 1200 MWe coal, and 1050 MWe nuclear.

A 300-MWe hydroelectric generating facility would likely inundate about 550 acres of land, resulting in associated land-use changes and the disturbance of associated terrestrial and aquatic biota.

Impacts from a 1200-MWe coal-fired generating facility result from mining, transportation, storage, combustion, and waste disposal. Typically, 400 acres of land is used for the coal-fired facility and 150 acres/year for surface mining (assuming the coal is supplied by surface mining of eastern coal). A possible 700 acre-ft of water is required annually in surface mining. Approximate amounts of pollutants discharged to the atmosphere (assuming the plant conforms to New Source Pollutant Standards) annually would be: SO_2, 28,000 tons; NO_x, 16,000 tons; particulates, 2000 tons; hydrocarbons, 3000 tons; CO, 1000 tons; lesser amounts of various metals; and about 23 Ci of radioactivity. These pollutants cause adverse health effects, primarily to the human respiratory system. Transportation of the coal from the mines to the generating plant causes increased traffic on the highways and railroads, resulting in increased accident potential, as well as increased emission from the internal combustion engines. Streams are polluted from surface mining operations, coal piles, and ash pits.

A 1050-MWe nuclear facility would require about 1500 to 2000 acres of land for the plant (250 acres) and buffer zone. About 5000 acre-ft of water is consumed annually, and terrestrial impacts result from cooling tower drift. As with coal mining, land is disturbed for uranium mining. Environmental issues related to uranium milling are sulfate emissions, low-level radiological releases, mill tailings disposal, and water consumption. The radiation dose to the surrounding population from the radioactivity released in nuclear plant effluents would increase possibly 2% over natural background levels.

The effects of potential accidents are evaluated. In the scenario where the entire contents of a 14-ton cylinder of UF_6 is released to the atmosphere within a 15-min time span, calculations show that lethal concentrations of HF could exist in the parking lot (open to the public) for a period of time. The concentration of HF would be 2300 mg/m^3; 1000 mg/m^3 is lethal. The radiation dose from the uranium released could result in a dose of 65 rem to the total body and 750 rem to the bone. The rupture of an anhydrous hydrofluoric acid storage tank could release twice as much HF to the atmosphere as the 14-ton UF_6 cylinder. All other accidents considered are more than an order of magnitude less severe.

1.6 UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECTS

Unavoidable adverse environmental impacts of ORGDP operation that may occur on the Oak Ridge Reservation near the plant are primarily a function of air quality deterioration. Under severe meteorological conditions, Tennessee ambient air quality standards for HF may be exceeded near the plant. Cooling tower plumes are visible offsite, and they occasionally touch the ground. The frequency of ground-level fogging along Tennessee Highway 58, adjacent to ORGDP, is estimated to be 16% greater than the frequency of fogging without plant operation.

The operation of ORGDP contributes to the chemical loading of Poplar Creek and the Clinch River. During periods of low flow or no flow, severe local aquatic impacts (toxicity, eutrophication) may occur, but the effects from such episodes should be transient, with the possible exception of increased heavy-metal body burdens in aquatic biota.

Operation of the plant through the year 2000 will use 20 acres of land for landfill disposal of radioactively contaminated wastes and 2 acres for sanitary wastes.

The total population living within 50 miles of ORGDP receives a total-body radiation dose of 0.044 man-rem/year. This is only about 0.00006% of the dose received by the population from natural background. Maximum-dose estimates for offsite individuals at the boundary fence 4 km SW of the plant are 0.0037 millirem/year for the total body and 0.00023 to 0.041 millirem/year for body organs. This does not add significantly to the individual's annual radiation dose from natural sources.

1.7 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Some of the resources committed to the continuing operation of ORGDP are irretrievable. These include gasoline and other fuels used primarily for transportation, fluorocarbon coolants that escape to the atmosphere, and chemicals used in water treatment. Materials contaminated with radioactivity that cannot be decontaminated are irreversibly committed. The electric power used to operate the plant, 2080 MWe, and the human labor, 4500 man-years/year, are irretrievable.

1.8 RELATIONSHIP OF LAND-USE PLANS, POLICIES, AND CONTROLS

The continuing operation of ORGDP does not conflict with local, state, or federal land-use plans and policies. Air and water pollutant discharges are regulated by various permits and are usually in compliance with stated standards. Any incidents of noncompliance are reported, and corrective measures are taken. Continuing operation is compatible with the intended use of the Oak Ridge Reservation.

1.9 RELATIONSHIP OF SHORT-TERM USES OF THE ENVIRONMENT AND LONG-TERM PRODUCTIVITY

The short-term use of the site — continued operation of ORGDP — will continue to supply enriched uranium for use in nuclear electric-power-generating facilities. Such reactors help diversify the power-generation industry and benefit the United States by decreasing the need for imported oil used in oil-fired facilities and by decreasing the demand for coal-fired facilities, which are major sources of air pollution.

The continued operation of ORGDP causes local effects through impacts on air, water, and land use. However, these effects are short-term and are offset by the positive economic benefits to the employees and surrounding communities. Long-term productivity should not be impaired since ultimate decommissioning of the plant could restore most of the environment to its original condition.

1.10 TRADE-OFF ANALYSIS

The major costs associated with the operation of ORGDP are environmental, whereas the major benefits are socioeconomic.

A critical evaluation of impacts found no threat to human life, no significant intrusion of toxic materials into the human food chain, and no evidence of major harm to local wild animals, birds, plants, or aquatic life. The socioeconomic benefits include (1) the amount of power made available to serve the nation, (2) a reduction in the U.S. balance-of-trade deficit througn income from separative work sales to foreign governments, (3) potential reduction of crude-oil imports, (4) environmental benefits from decreased use of coal for power generation, and (5) benefits to the local economic system because of plant payroll and purchases.

2. DESCRIPTION OF OAK RIDGE GASEOUS DIFFUSION PLANT

2.1 PURPOSE AND NEED

After almost three decades of development, nuclear energy has been determined to be a practical means of helping to meet the nation's electric power requirements. In fact, a substantial nuclear power industry is already well established with more than 200,000 MW of capacity committed at this time. Energy requirements are predicted to grow at a rate of 3.0% to 3.5% per year until the year 2000.[1] Even if new nonnuclear technologies currently under study can be successfully developed, the nuclear option must be maintained until at least 2000 to meet these increasing energy demands.

Uranium is expected to be the primary source of fuel for nuclear power reactors during the remainder of this century.[1] The conventional light-water reactors require uranium enriched to a nominal uranium-235 content of 3%. Since natural uranium contains only 0.7% uranium-235, an enriching process is needed to provide reactor fuel. Enrichment is currently provided by the gaseous diffusion process, which is carried out in three plants operated for the U.S. government. The plants are located near Piketon, Ohio;[2] Paducah, Kentucky; and Oak Ridge, Tennessee. Operation, projected to 1984, of the Oak Ridge Gaseous Diffusion Plant (ORGDP), Oak Ridge, Tennessee, is the subject of this assessment.

2.2 DESCRIPTION OF ORGDP OPERATION

2.2.1 Historical

Although the gaseous diffusion process was first conceived by Graham in 1892 and later used by Aston in 1920 and Hertz in 1936 to separate the isotopes of neon, the large-scale separation of the uranium-235 isotope was not visualized by scientists until 1940. Sparked by the possibility of constructing nuclear weapons to use in World War II, an extensive research project on such separation was begun at Columbia University, New York, in 1941. Two years later, construction of a diffusion facility for the large-scale separation of uranium-235 was begun in Oak Ridge, Tennessee. By August 1945, this facility, known as the K-25 Diffusion Cascade, was in full operation. By 1956, four additional process buildings (K-27, K-29, K-31, K-33) were on line enriching uranium.

After the war, the nation's nuclear energy emphasis was directed toward the peaceful goal of providing electric power. As a result of this decision, the operating philosophy was changed to provide uranium compatible with power reactors.

At the time of this assessment, the diffusion plant is being upgraded and uprated to provide additional enrichment capability. In addition, extensive effort is being expended on the development of alternative enrichment processes. Particular emphasis is being placed on the gas centrifuge process, with facilities now being constructed to house pilot-plant-scale operations. As a result of this increased activity, plant employment has grown to about 7000. After the diffusion uprating program is completed and ORGDP is operating at full power (about 1984), a steady-state level of about 4500 employees should be reached.

2.2.2 Location and external appearance

The ORGDP is situated on a level 640-acre tract of land bounded on the north by Blair Road, on the west by the Clinch River, and on the south and east by Tennessee Highway 58 (Figs. 2.1 and 2.2). Poplar Creek flows from northeast to southwest through approximately the center of the plant area.

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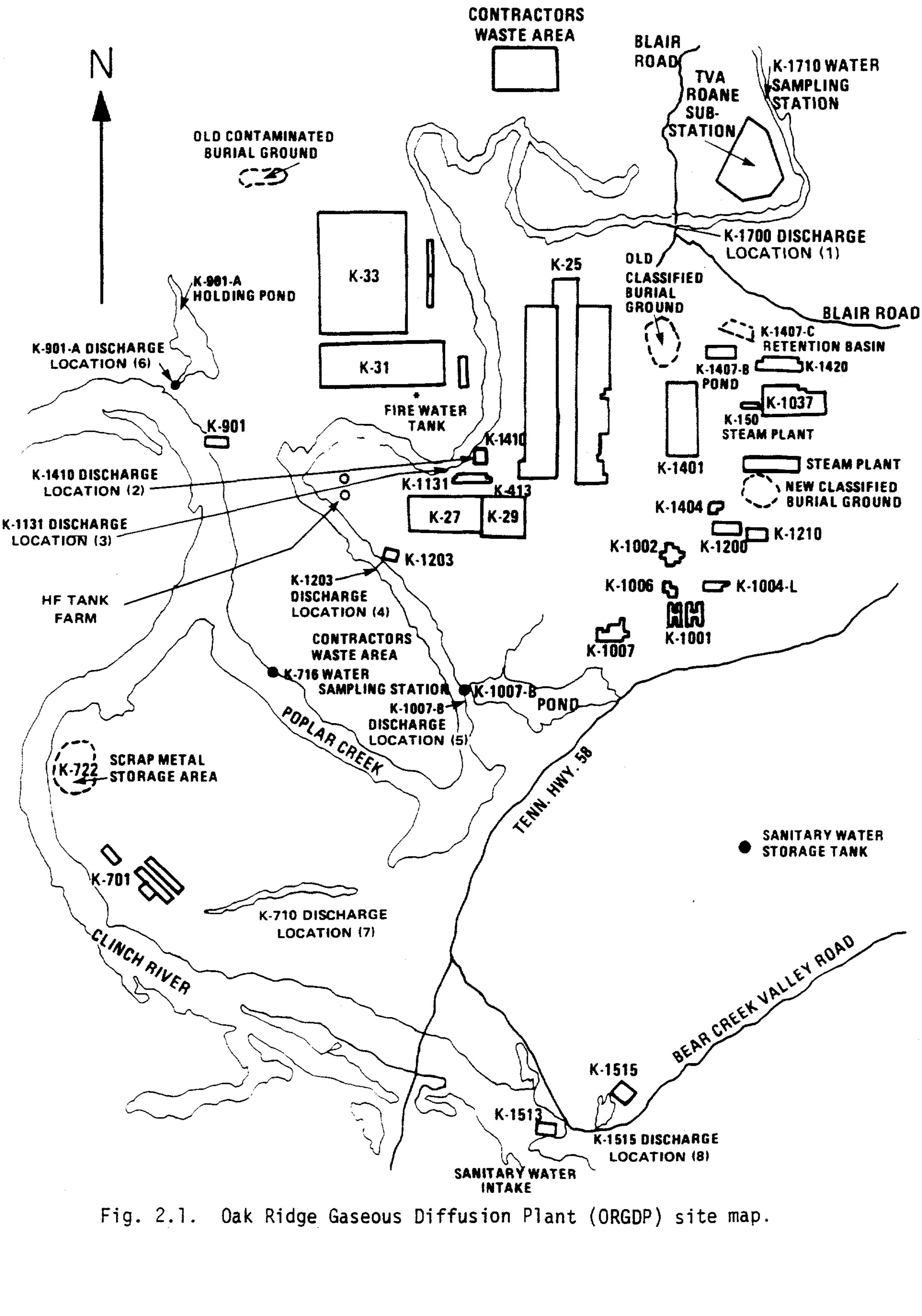

Fig. 2.1. Oak Ridge Gaseous Diffusion Plant (ORGDP) site map.

Fig. 2.2. Aerial view of ORGDP (view from east-northeast to west-southwest).

Figure 2.1 shows the five largest buildings — K-33, K-31, K-27, K-29, and K-25 — the diffusion process facilities. The K-27 building is in standby condition, and the K-25 building is used only as a warehouse; thus, neither is involved in the enrichment process. The buildings located in the southeastern region of the plant (K-1200, K-1210, K-1023, K-1052, and K-1010) house the gas centrifuge projects. Building K-1401, located in the mideast area of the plant, is used for fabrication and maintenance of equipment. In Building K-1420 (extreme northeast corner) equipment is decontaminated prior to maintenance; here, also, the uranium removed during the decontamination process is recovered. Located just south of K-1420 is Building K-1037, where the diffusion-process barrier material is manufactured. The remainder of the facilities shown in Figs. 2.1 and 2.2 house support groups such as administrators, data analyzers, laboratories, and supply stores.

Two areas maintained by, but not located within ORGDP proper, are the old powerhouse area and the sanitary water treatment facility (Fig. 2.1). The powerhouse was once, as its name implies, the producer of part of the electrical energy requirements of ORGDP. Since these requirements are now met by the Tennessee Valley Authority (TVA), the majority of the facilities in this area were decommissioned. The buildings are now used for salvage storage, training of welders, and engineering offices. The sanitary water treatment facility (K-1515), located about 1 mile (1.6 km) south of the plant proper, on Bear Creek Road, consists of typical water treatment equipment, such as settling basins and concrete storage tanks.

The only thoroughfares providing access to the plant site are Blair Road from the north and Tennessee Highway 58 from the northeast and southwest (Fig. 2.1). The most distinct features viewed from either of these routes are the plumes of condensed water vapor above the cooling towers used to cool the plant's process water and the 360-ft-high (110 m) red and white fire-protection-water storage tank. A traveler viewing ORGDP from Blair Road (north of the plant) would also see the two 170-ft-high (52 m) smoke stacks of the plant's steam plant, whereas anyone passing by on Highway 58 (south of the plant) would see the large grassy areas and the lakes that border the front of the plant. All these features can be viewed clearly from the ORGDP overlook located just south of the plant on Highway 58.

2.2.3 Facilities

To more clearly describe the various physical facilities of ORGDP, they have been categorized as (1) those directly involved in the enrichment process, (2) those providing support to all plant activities, including development facilities, and (3) those directly associated with the treatment and/or discharge of pollutants.

2.2.3.1 Enrichment facilities

Figure 2.3 illustrates the basic concept of the gaseous diffusion process; it shows schematically what takes place in a single stage. The uranium, which exists as gaseous uranium hexafluoride (UF_6), is forced to flow through the inside of a porous membrane called barrier. About half the gas diffuses through the barrier and is subsequently introduced into the next higher stage, while the remaining undiffused portion flows to the next lower stage. The diffused stream is slightly enriched in uranium-235, and the undiffused stream is depleted in uranium-235 to the same degree.

Figure 2.4 shows how the individual stages are connected to accomplish the desired enrichment levels. This figure also indicates the basic process equipment components. Axial flow compressors driven by electric motors compress the UF_6 to maintain interstage flow.

A gas cooler is provided for each stage because gas compression generates heat that must be removed. The diffuser, or converter, is the large cylindrical vessel that contains the barrier material.

When operating at full capacity in 1984, the plant will require about 2080 MWe to operate this equipment. This power is procured from TVA and is delivered to the ORGDP switchyards over 161- and 500-kV transmission lines. The transmission lines and related power distribution systems are described in greater detail in Sect. 2.3.

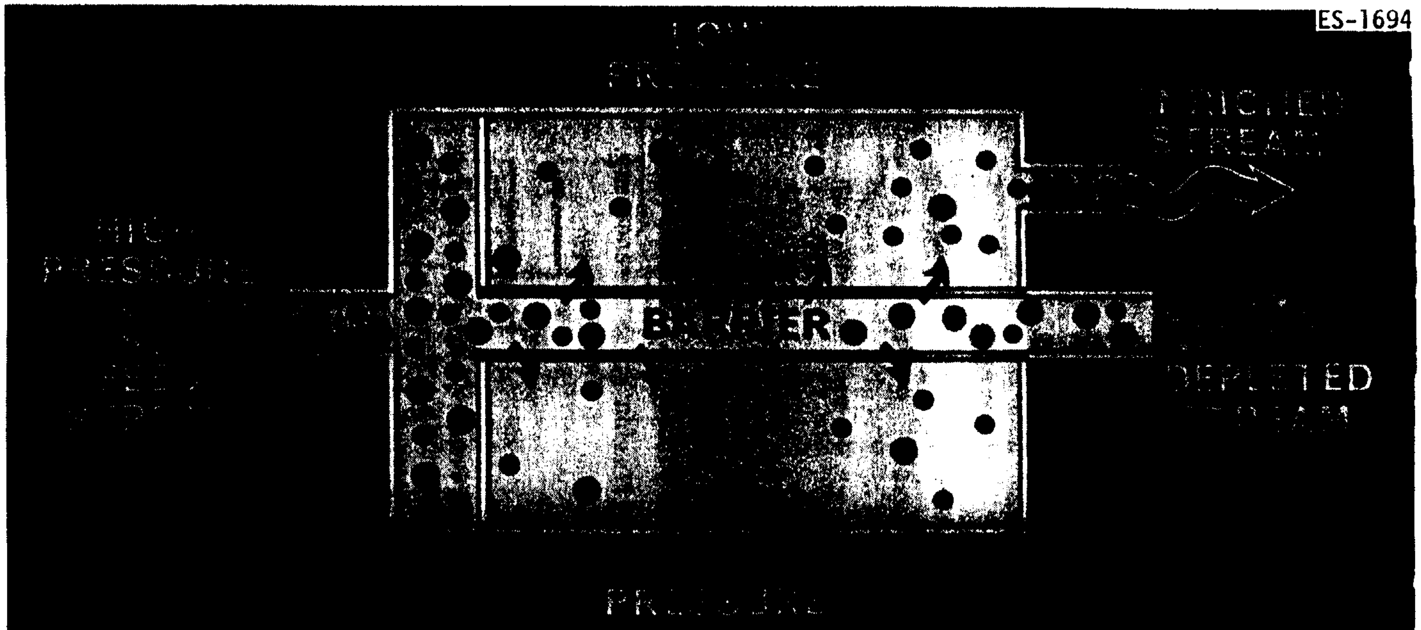

Fig. 2.3. Gaseous diffusion stage.

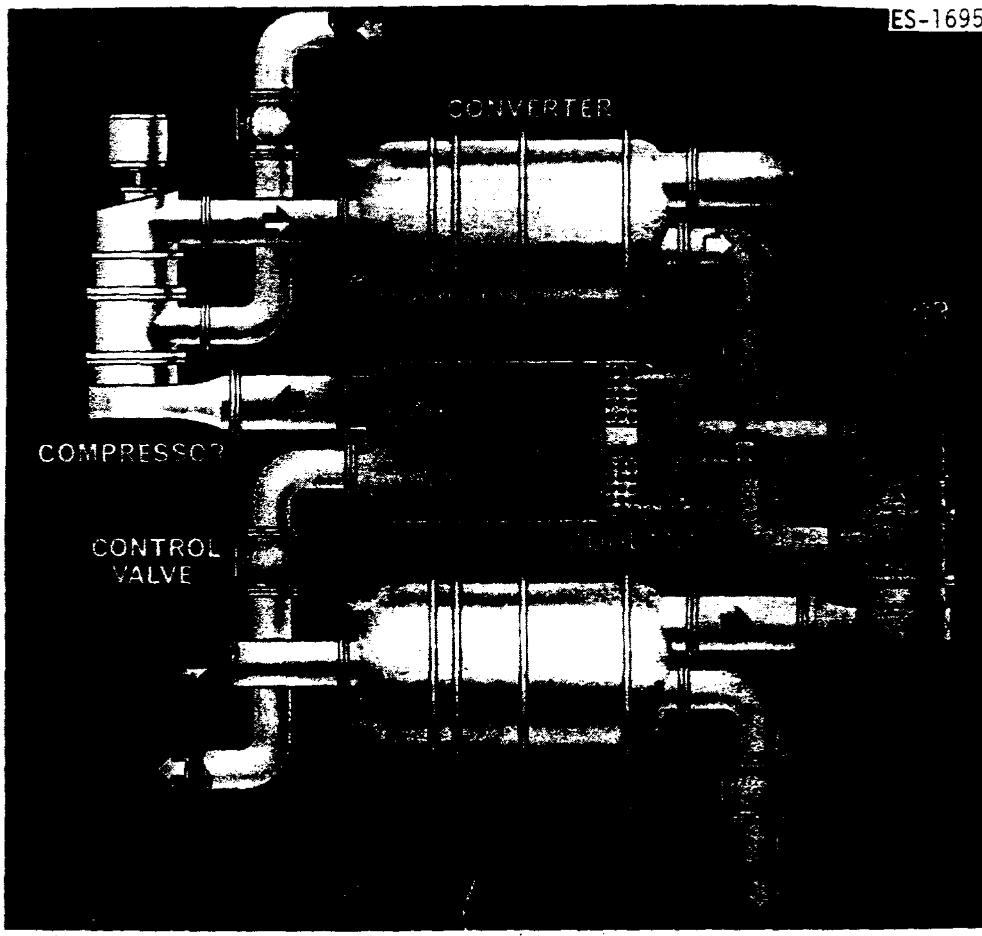

Fig. 2.4. Diffusion stage arrangement.

Figure 2.5 is a flow diagram of the ORGDP enrichment cascade. From the figure it can be seen that several auxiliary operations are also required to effect the desired enrichment of uranium. One such operation is housed in Building K-1131. In this feed facility, normal feed consisting of solid UF_6 is heated to the gaseous state in large steam-heated autoclaves, from whence it flows into the first stage of the diffusion cascade, located in Building K-33. Paducah product feed is fed to K-31. By 1984, an improved facility capable of handling the increased flow of UF_6 will have been installed. This new facility, the flow diagram for which is shown in Fig. 2.6, will use five pairs of steam-heated autoclaves for converting the UF_6 to a gas. Two pairs of these autoclaves will be dedicated to normal-assay-feed material; one pair will be dedicated to product feed from the Paducah Gaseous Diffusion Plant (PGDP); one pair will be capable of feeding either reactor returns material or preproduction stockpile feed; and the fifth pair will be used to increase the feed rate during rapid power increases. Rapid power increases are necessitated by short notice of availability of power by TVA.

Note that this system was designed prior to the decision not to recycle uranium through the fuel cycle. Therefore, it will contain provisions for feeding reactor returns material, including traps for removing transuranics and fission products. However, since such materials will not have to be removed, the traps will not accumulate high concentrations of radioactive materials. Thus there is no further discussion of the traps. (A discussion of such traps, including operating characteristics and measures taken to prevent accidents, can be found in ref. 1.) All the proposed autoclaves, except the normal-assay-feed autoclaves, are rated at 150 psig, thus enabling them to contain a gaseous release from a ruptured feed cylinder, should the need arise. Such releases could then be collected by existing cleanup equipment and processed in the uranium recovery facility.

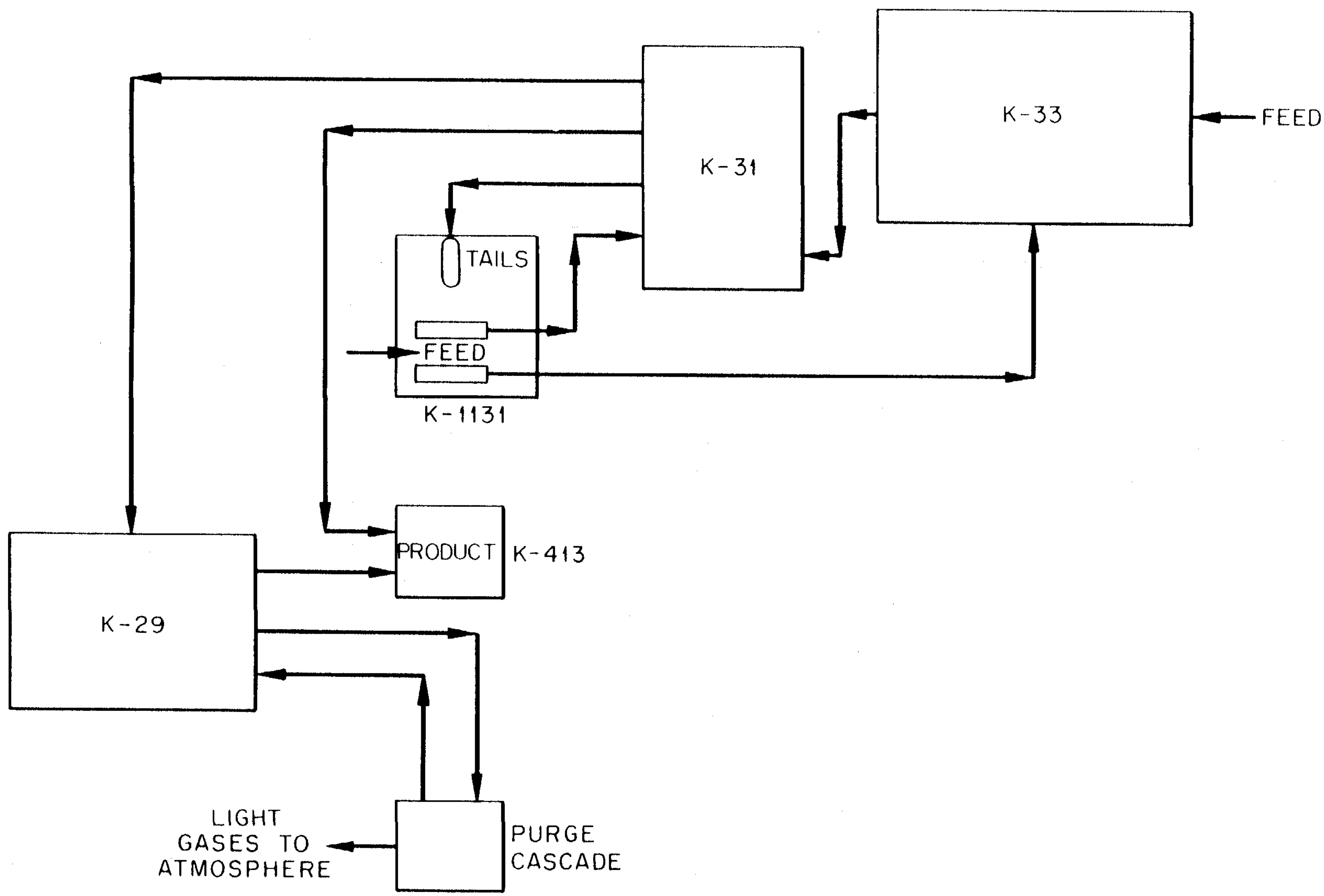

Fig. 2.5. Flow diagram of diffusion cascade.

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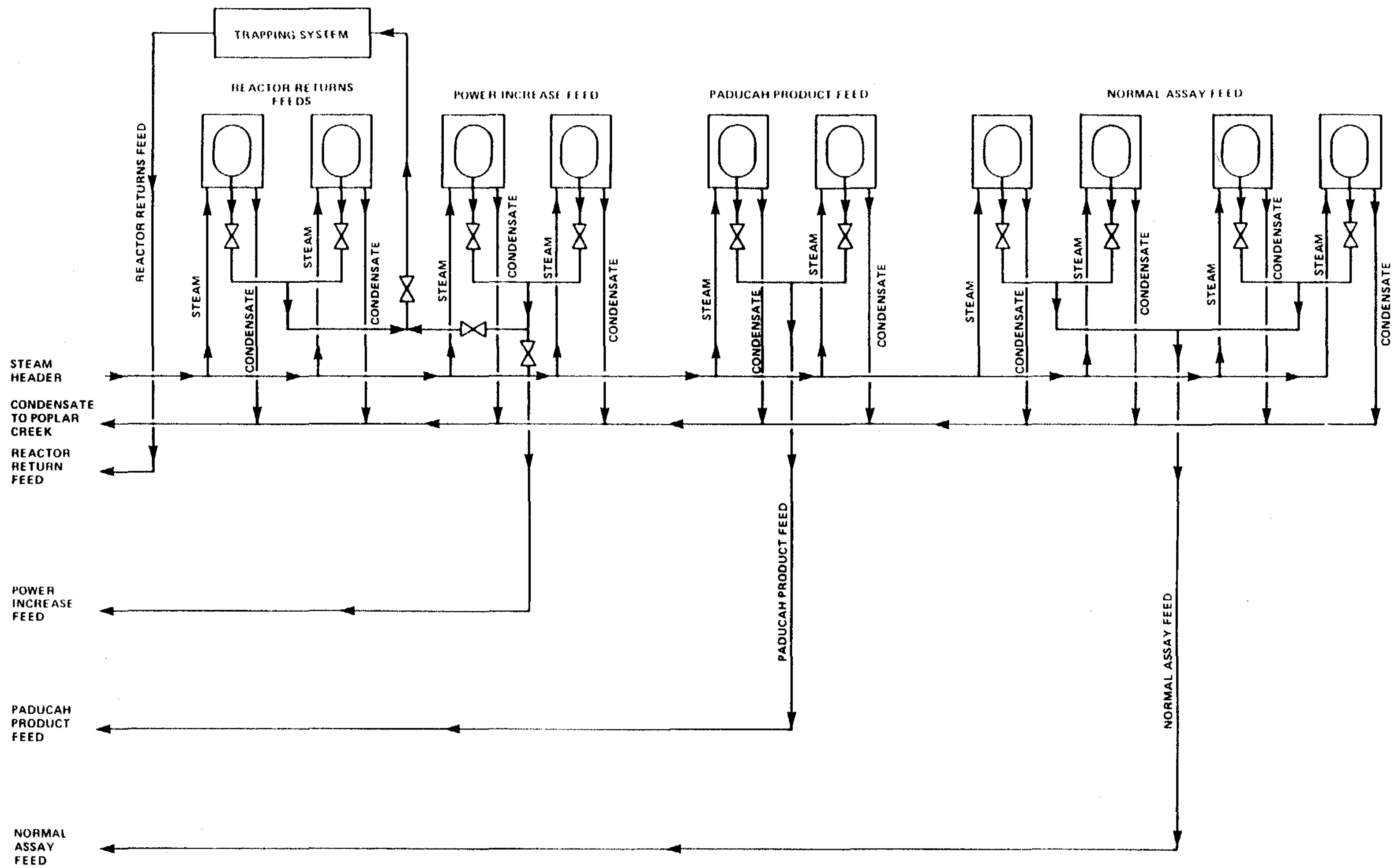

Fig. 2.6. Flow diagram of proposed diffusion feed facility.

Removal (withdrawal) of the enriched and depleted UF_6 from the cascade is effected through facilities located in Buildings K-413 and K-1131 respectively (Fig. 2.1). Both streams will be withdrawn by compressing and subsequently condensing the UF_6 to the liquid state, after which it will be allowed to flow into 10- or 14-ton cylinders where it will cool and solidify. The depleted UF_6 currently is stored as a solid in these cylinders. A flow diagram of the tails withdrawal system is shown in Fig. 2.7, and that for the product is shown in Fig. 2.8.

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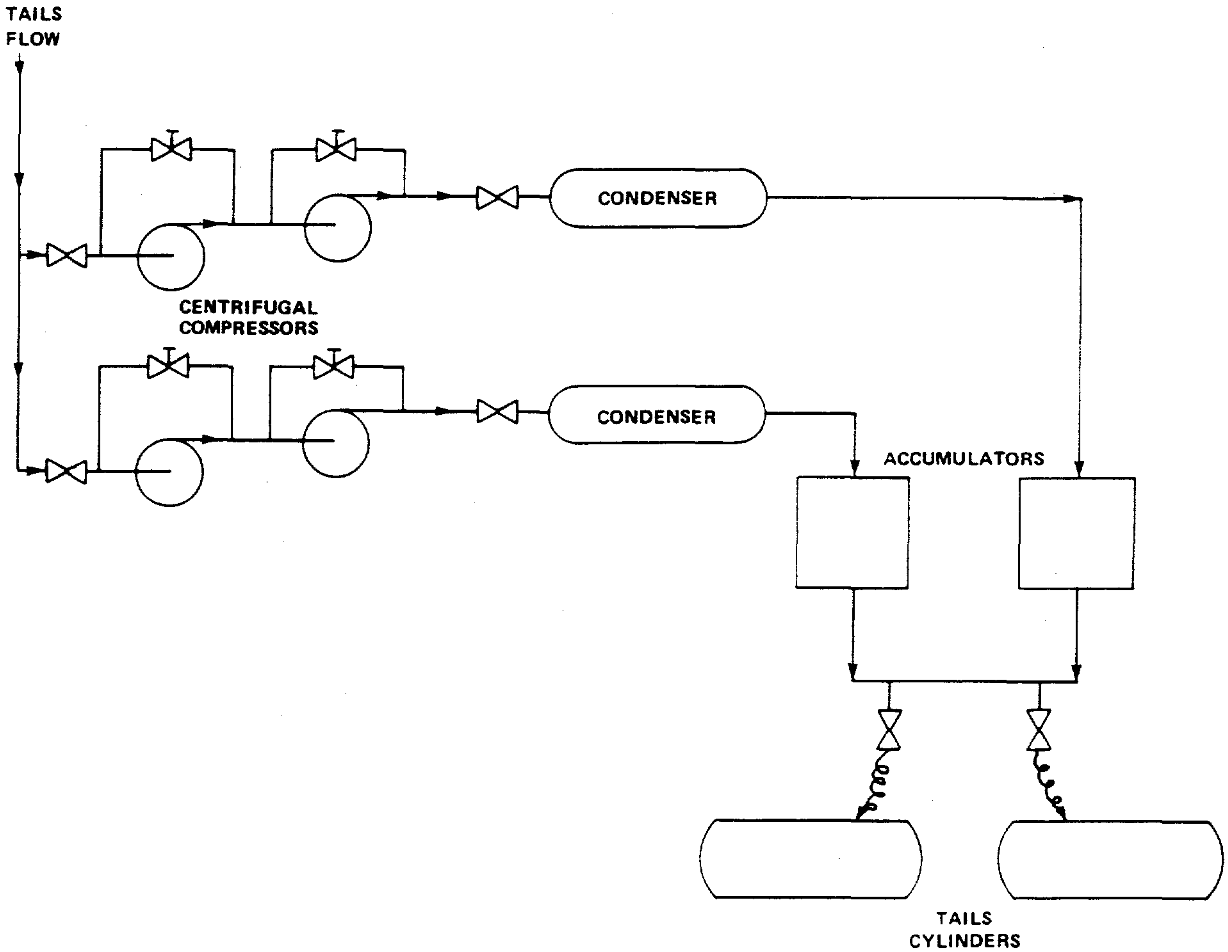

Fig. 2.7. Flow diagram of diffusion tails withdrawal system.

Because the diffusion cascade operates at below atmospheric pressure, light gases such as nitrogen, coolant, and air routinely leak into the system. Since these gases are much lighter than UF_6, they are readily transferred to the top of the cascade where they would, if not removed, block the flow of enriched UF_6 to the product withdrawal point. To prevent this blockage, the light gases are separated from the UF_6 and, after treatment, discharged to the atmosphere. The facility used for this separation is called the purge cascade (Fig. 2.5) and is located in Building K-27 (Figs. 2.1 and 2.2). This facility consists of equipment similar to that used in the rest of the cascade, but it is designed to handle the lighter gases. Since the coolant gases, which enter the system from leaks in the gas coolers, are heavier than nitrogen and air but lighter than UF_6, they must be withdrawn through a parallel or side stream. As seen in Fig. 2.9, the effluents from both systems are passed through chemical traps and through a wet potassium hydroxide scrubber to reduce residual levels of uranium and fluorine compounds before discharge to the atmosphere. The magnesium fluoride traps located within the system remove technetium-99, a fission product which entered the ORGDP diffusion cascade when production reactor returns material was introduced several years ago. There are no plans in the near future to introduce any more production reactor returns into the cascade.

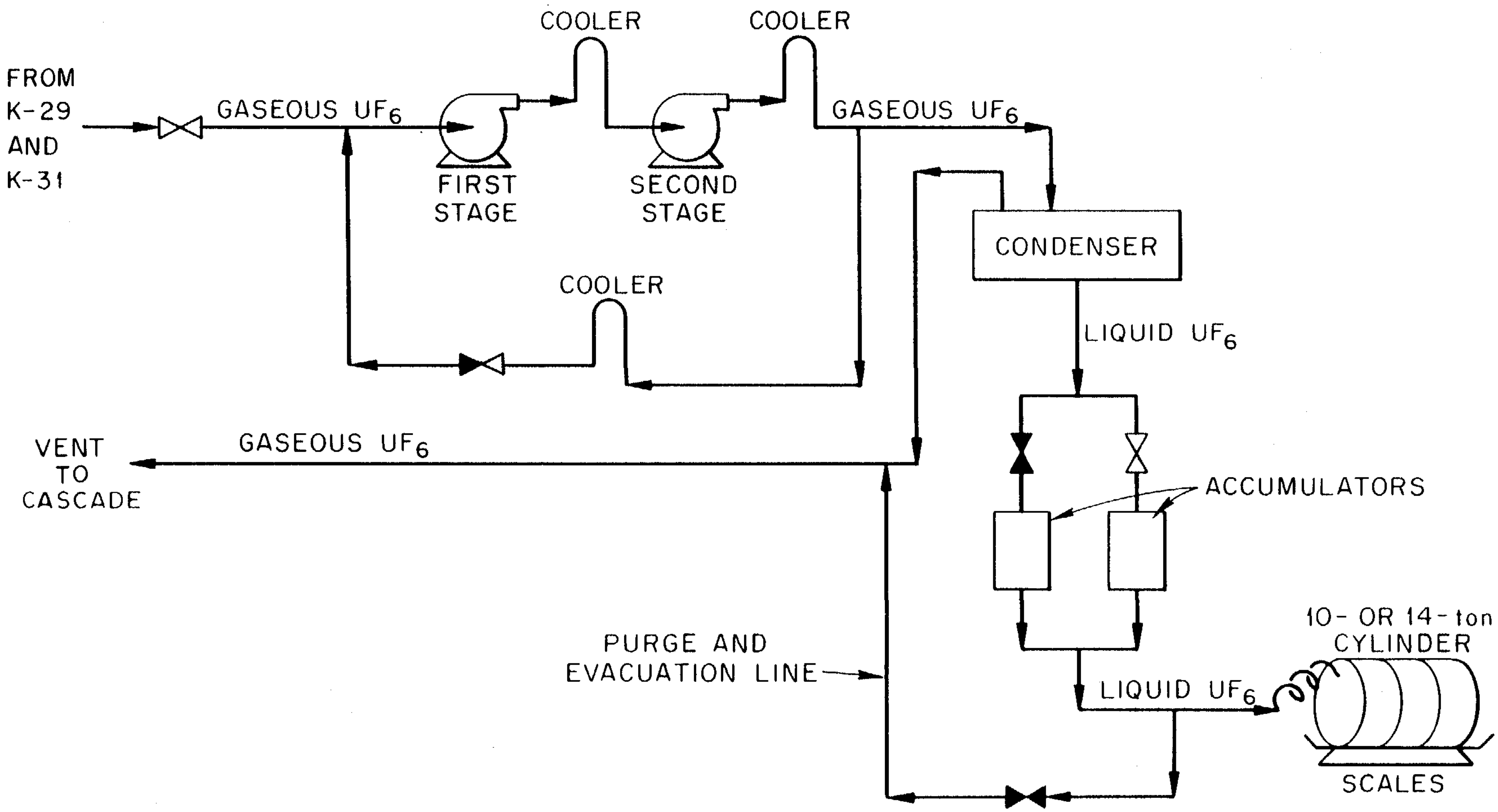

Fig. 2.8. Flow diagram of diffusion product withdrawal system.

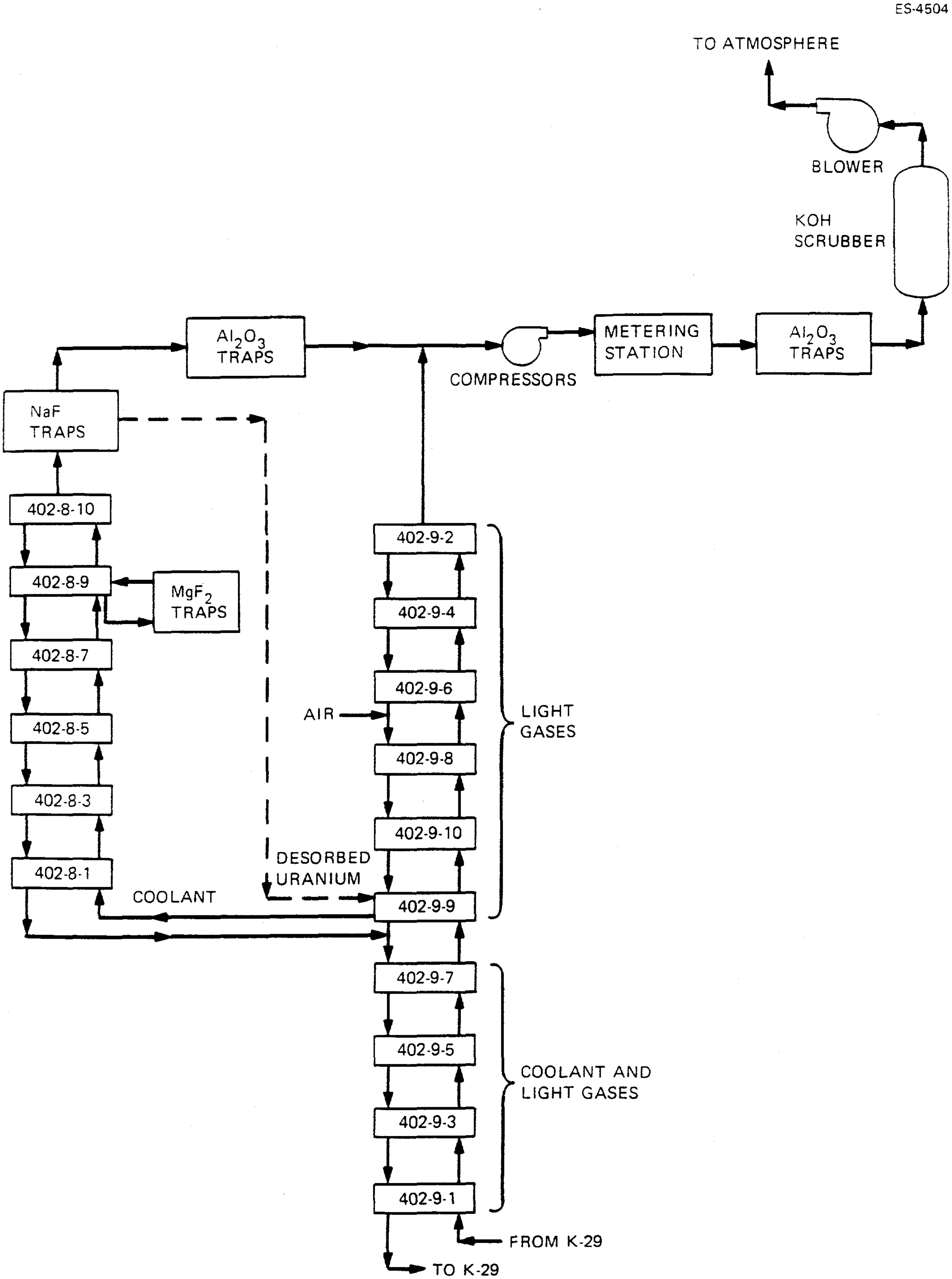

Fig. 2.9. Flow diagram of the ORGDP purge cascade.

2.2.3.2 Support facilities

In addition to the gaseous diffusion process facilities, the ORGDP site also houses several support or auxiliary facilities. The functions of these operations range from providing direct support to the diffusion process to the development of alternative enrichment processes. The facilities are listed below.

1. Gaseous diffusion development facilities, including a pilot plant
2. Analytical laboratories
3. Gas centrifuge development facilities, including two pilot-plant-scale operations
4. Steam generation facility for providing both process and space heating
5. Nitrogen production facility for process purging operations and laboratory uses
6. Air compressors to meet the needs of instrumentation and air-operated equipment
7. Fluorine production plant, including hydrogen fluoride (HF) storage facilities
8. Plant for production of barrier, the porous diffusion membrane
9. Facilities for
   a. receiving, shipping, and sampling of UF_6
   b. decontamination of equipment and subsequent recovery of uranium
   c. cleaning of metals used throughout ORGDP
   d. plating of metal parts
   e. spray painting
   f. woodworking
   g. rebuilding of motors
   h. manufacturing of small plastic parts
   i. sewage treatment
10. Recirculating process cooling water system
11. Sanitary (potable) water system
12. Burial grounds
13. Laundry for cleaning personnel clothing

Most of the these facilities generate insignificant quantities of wastes. Those that produce significant quantities of wastes are equipped with appropriate waste treatment systems to prevent substantial releases to the environment. A brief description of each of the larger waste producers is provided in the following paragraphs.

Gaseous diffusion pilot plant

The diffusion pilot plant is a small, highly instrumented, multistage cascade operated under conditions of total UF_6 recycle. The primary purpose of this facility is to test the separative efficiency of barrier over a wide range of temperatures and pressures. The maximum quantity of UF_6 contained in the system at any one time is about 25 lb (11 kg). Airborne releases from this operation consist primarily of gaseous fluorides which are passed through alumina traps prior to release to the atmosphere. By 1984, additional fluoride removal equipment will have been installed. The quantities of materials to be released from this facility are reflected in the effluent descriptions presented in Sect. 2.2.3.3.

Centrifuge development facilities

The gas centrifuge program of ORGDP is actively pursuing the development of an alternative technology for the enrichment of uranium. As does the diffusion process, the centrifuge process handles uranium as gaseous UF_6. Through the cascading of a few centrifuges, the desired enrichment level can be attained.

The primary efforts of the ORGDP program are aimed at machine development, reliability, productivity, and operability. To achieve the desired results, several facilities have been constructed for developing machine production techniques, long-term reliability, and equipment cascading. The quantities of effluents from all these facilities are extremely small (see Sect. 2.2.3.3).

Steam plant

The ORGDP steam plant generates steam used for process purposes and for space heating. This facility has seven fossil-fueled boilers with a combined steam-producing capacity of 370,000 lb/hr. In 1984, five of the boilers — three rated at 40,000 lb/hr and two rated at 50,000 lb/hr — will be fired exclusively with coal. One boiler can be fired with either coal or natural gas. The other boiler, rated at 100,000 lb/hr, is designed to burn natural gas or fuel oil.

Gaseous emissions from the steam plant consist of the normal fossil fuel combustion products, specifically, sulfur dioxide (SO_2), oxides of nitrogen (NO_x), hydrogen fluoride (HF), and particulates. (See Sect. 2.2.3.3 for a quantitative description of these constituents.) Electrostatic precipitators recently have been installed to reduce the particulates discharged from the coal-fired boilers, so that they are now in compliance with Tennessee and Clean Air Act standards for particulates as well as for visible emissions. The particulate standard requires that no more than 0.1 lb of particulates be discharged for each 1,000,000 Btu of heat input. With the precipitators in operation, the particulate discharge rate, based on recent stack-gas emission tests, is about 0.075 lb/1,000,000 Btu. The visible emission standard requires that the opacity of the stack-gas effluent be visibly determined to be $\leq$20% for $\leq$5 min in any 1-hr period or for $\leq$20 min in any 24-hr period. The SO_2 releases from the steam plant are maintained within the state limit of 5.0 lb/1,000,000 Btu of heat input by burning coal containing less than 2.7 wt % sulfur. For example, burning of coal that contains 2.7 wt % sulfur will produce about 4.7 lb/1,000,000 Btu. Radioactivity is also released from fossil-fuel plants (see Table 5.28).

The primary liquid effluents from the steam plant consist of the acidic discharge from the supply water treatment operation and the caustic boiler water blowdown. These discharges are combined and neutralized before release to the K-1407-B holding pond. Settleable solids collected in the pond are removed about every ten years. After 1984, these solids will be "chemically fixed" and stored aboveground in concrete casks.

A weak sulfuric acid runoff from the coal storage yard occurs after heavy rains. This solution is collected by a dike-and-ditch arrangement and subsequently piped to the K-1407-A neutralization pit or diverted around the pit into Poplar Creek, depending on the solution's pH and flow rate.

The ash resulting from coal combustion is the only solid waste generated by the steam plant. During the peak coal-burning months (January and February), the ash will be generated at a rate of about 35 tons per day. This material is collected dry and deposited in local landfill areas.

Fluorine plant

The ORGDP produces fluorine, which is used primarily for treating various pieces of equipment, in Building K-1131 (Fig. 2.1). The process consists of the electrolysis of an aqueous solution of potassium bifluoride and hydrogen fluoride in five electrolytic cells using dc electricity and carbon electrodes. The electrolysis produces two gaseous products — hydrogen and fluorine — which are withdrawn separately. Each product stream also contains from 0% to 14% HF. The fluorine is passed through filters to remove electrolyte, a condenser to remove HF, and distributed to plant users. The hydrogen is currently vented directly to the atmosphere, but, by 1984, it will be passed through a fluoride removal system prior to discharge. The quantities released from this process are given in Sect. 2.2.3.3.

HF tank farm

Anhydrous HF is stored at and distributed from the K-1132 HF tank farm (Fig. 2.1). The material is received by rail and stored as a liquid in 10,000-gal storage tanks. The tanks, constructed of 5/8-in.-thick steel, are equipped with valves and piping for transferring the HF by air pressure to the K-1131 facility. Currently, a maximum of 160,000 lb (72,500 kg) of HF is stored onsite at any one time. The tank farm is covered by a roof and contained by a dike capable of handling the entire storage capacity. Any spill into the dike would flow through a sump and into an underground tank. Accidental releases are discussed in Sect. 2.2.5.6.

Normal releases from the HF tank farm occur only when sections of the piping are vented. Since this effluent is passed through a solid-bed scrubber, discharge to the atmosphere is minimal.

Barrier plant

Building K-1037, just east of the steam plant in the northeast corner of the ORGDP site, is the barrier manufacturing facility. It is a unique facility since it is the only location in the United States where the barrier material is manufactured. This material is the heart of the gaseous diffusion process, so virtually every detail of its composition and manufacture is classified. Effluents from this facility are included in the discussion presented in Sect. 2.2.3.3.

Decontamination and recovery facility

Equipment used in the gaseous diffusion and gas centrifuge processes is subject to gradual deposition of uranium-bearing compounds. When equipment is removed from the system, it must be decontaminated to meet radiation standards before maintenance functions can proceed. Decontamination is done in Building K-1420 (located in the northern region of the ORGDP site, northeast of the steam plant) (Fig. 2.1).

The primary method for cleaning the process equipment includes some form of mechanical removal in combination with cleaning solutions of water, steam, weak nitric acid, or sodium carbonate. The waste cleaning solutions normally contain uranium in addition to other metals such as aluminum, copper, iron, magnesium, manganese, and nickel.

Cleaning solutions are collected in tanks that are designed to prevent the possibility of a critical-mass event and then transferred to the uranium recovery facility located in the same building. The recovery process consists of a solvent extraction purification step followed by concentration, drying, and calcining to produce uranium oxide (as U_3O_8 and UO_3), which is reintroduced into the uranium fuel cycle. About 2400 kg of uranium per year is currently shipped to UF_6 production facilities. Since this material is in solid form and is of a low enrichment (<3% uranium-235), transportation risks are minimal.

The primary liquid effluents from the decontamination and recovery facility emanate from the solvent extraction step. The waste stream from this purification operation is highly concentrated with nitrates and also contains small concentrations of uranium and technetium compounds. Currently, this waste is transported to the Y-12 Plant to a facility where the nitrates are biologically decomposed. Wastes from the biodenitrification facility are deposited in a large retention basin. The impacts of the Y-12 biodenitrification facility and retention basin will be discussed in the Y-12 Environmental Impact Assessment (EIA) (in preparation).

The quantity of airborne effluents from the decontamination and recovery facility is very small, and the primary constituents are uranium-bearing particulates and oxides of nitrogen. The K-1420 effluents are described in Sect. 2.2.3.3.

Metals cleaning facility

The metals cleaning facility located in Building K-1401 (Fig. 2.1) is used to prepare various metals for numerous fabrication and assembly operations. The primary method for accomplishing such preparations involves the use of cleaning baths containing hydrochloric acid, sodium hydroxide, and trichloroethane. The acid and caustic solutions are neutralized in the K-1407-A neutralization pit prior to discharge to the K-1407-B pond, where the precipitated metallic hydroxides are allowed to settle. The liquid effluent from the pond enters Poplar Creek via the K-1700 discharge (Fig. 2.1).

Nickel-plating facilities

To combat the corrosive nature of UF_6, diffusion process equipment at ORGDP is nickel-plated in two small facilities that provide routine plating services. One is located in Building K-1410 (Fig. 2.1) and uses the standard Watts nickel sulfate solution in an 8000-gal electroplating tank. In addition to the plating process, this operation involves the cleaning of parts to be plated. Cleaning solutions normally used include aqueous solution of 25% hydrochloric acid, 75% sulfuric acid, and two proprietary caustic detergents. Rinse tanks are provided to rid parts of both the cleaning and plating solutions.

Liquid effluents from the electroplating facility consist solely of the rinse solutions. Since these discharges are intermittent, they are pH adjusted through an automatic flow equalization pit, which is located just west of Building K-1410.

The other ORGDP nickel-plating facility consists of a small electroless operation located in Building K-1420. This process relies on chemical deposition for transferring nickel to the metal parts. As with the electroplating operation, metal cleaning and rinsing are important parts of the process. The rinse flows are piped to the K-1407-A neutralization pit for pH adjustment, and the plating bath and cleaning solutions are periodically transported to the Y-12 biodenitrification facility.

2.2.3.3 Environmentally related systems

The various types of effluent treatment and discharge facilities have, for reporting convenience, been categorized by systems: (1) heat dissipation, (2) radioactive waste, (3) chemical waste, (4) sanitary waste, and (5) storm drain. This section presents a brief description of each and the monitoring programs that characterize them.

Heat dissipation systems

Excess heat in the gaseous diffusion cascade is removed by a recirculating cooling water system and subsequently dissipated to the atmosphere via mechanical-draft cooling towers. This type of heat dissipation has been used since the startup of ORGDP in 1945. The basic flow diagram for the system is shown in Fig. 2.10.

Raw water is taken from the Clinch River through the K-901 pumphouse and pumped to the K-892 clarification facility where lime, soda ash, and organic coagulants are added to remove calcium and magnesium as well as ordinary suspended solids. After clarification, the water used directly by the diffusion process is treated with a hexavalent chromium (Cr^{6+}) compound to inhibit corrosion of the heat transfer equipment. This treated water is subsequently transferred to the three primary cooling loops — K-33, K-31, and K-29. Through recycling within each loop, process heat is removed and dissipated to the atmosphere via the cooling towers. The coagulant sludge is discharged into the K-901-A holding pond.

As shown in Fig. 2.10, secondary cooling systems and the fire-protection-water system are supplied with clarified nonchromate water. Besides the normal fire hydrant flushing, the only other liquid effluent from these systems is that from the K-1037 (barrier plant) cooling tower, which enters Poplar Creek through the K-1700 discharge.

By 1984, the ORGDP electrical load will be about 2080 MWe, more than 90% of which will be dissipated as heat through evaporation from the mechanical-draft cooling towers. To replenish the water loss from evaporation, drift, and liquid blowdown, about 75 Ml/day (20 Mgd) of water will be taken from the Clinch River. Withdrawal will be effected by the K-901 pumping station located due west of the ORGDP site (Fig. 2.1). Debris will be prevented from entering the system by an inverted weir in conjunction with trash racks and traveling trash screens. The velocity of the water flow at the face of the trash racks will be about 6 cm/sec (0.2 fps). A similar system will be used to withdraw an additional 4 Mgd of water from the Clinch River for potable usage.

Due to the high rate of evaporation from the recirculating cooling water, dissolved solids (primarily calcium, magnesium, sulfate, and chloride compounds) concentrate in the cooling water. If not removed, these solids deposit on the heat transfer equipment and significantly reduce its effectiveness. To prevent deposition, a portion of the flow is diverted through a blowdown softener where calcium and magnesium are precipitated, allowed to settle, and removed to the K-901-A holding pond. The softened water is then reintroduced into the cooling cycle. This system, along with the solids removal afforded by ordinary cooling tower drift losses, has enabled the ORGDP process cooling system to function with a minimal amount of liquid blowdown. The blowdown stream is currently passed at 280 liters/min (75 gpm) through an electrolytic reduction facility, where the soluble Cr^{6+} is reduced to the trivalent state and

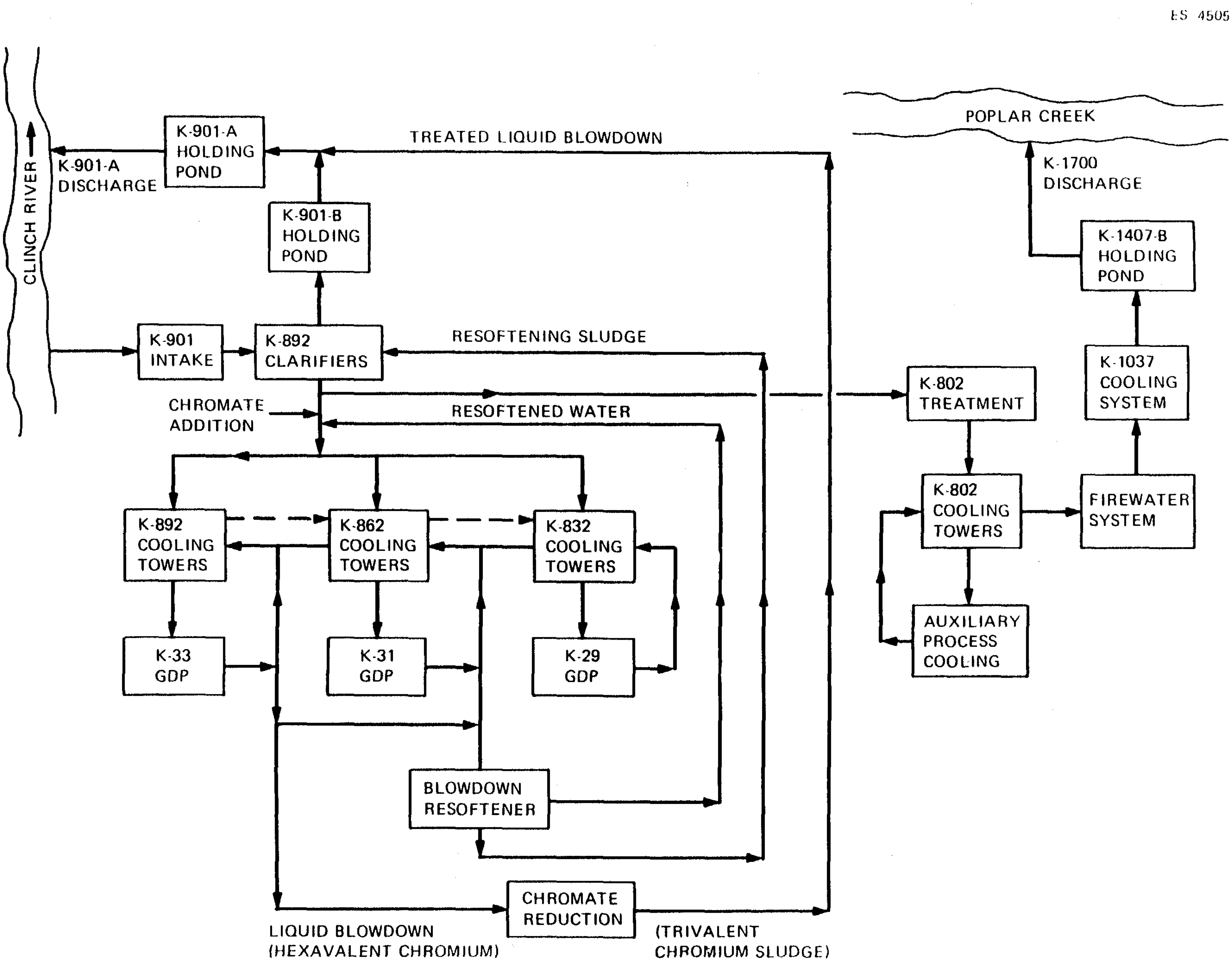

Fig. 2.10. Flow diagram of the ORGDP recirculating cooling water system.

precipitated as a ferrous-chromium hydroxide complex. This precipitate is then transferred to the K-901-A pond and allowed to settle.

The K-901-A pond discharge, which also contains flow from small springs and surface runoff, enters the Clinch River at about 5000 liters/min (1300 gpm). Although the pond also serves as a heat dissipation medium, the temperature of its effluent is only 1.7° to 3.3°C (3° to 6°F) above the ambient Clinch River temperature. The plume it produces in the river can be detected only about 12 to 18 m (40 to 60 ft) from the discharge point. Its width is from 6 to 9 m (20 to 30 ft) and its maximum depth is less than 1 m (3 ft), which is less than half the distance from the bottom of the river at that point.

To better understand the impacts of the airborne effluents from the ORGDP cooling towers, a study[3] was conducted in 1972 and 1973 to determine:

1. drift and associated chemical losses from the cooling towers
2. extent of drift deposition on the terrestrial environs
3. impact of drift deposition
4. relative sizes of plumes emanating from the towers
5. impact of the gaseous plumes on local weather conditions.

Participants in the study included the Oak Ridge National Laboratory; the Oak Ridge Y-12 Plant; the Oak Ridge Gaseous Diffusion Plant; the Environmental Systems Corporation of Knoxville, Tennessee; the Atmospheric Turbulence and Diffusion Laboratory of the National Oceanic and Atmospheric Administration; and the Pacific Northwest Laboratory, which is operated by Battelle Memorial Institute. A summary of the results of the study is presented below.

Drift losses were found to be in general agreement with losses reported from similar towers of the same age and ranged from about 0.001% of the recirculating flow for the K-33 tower to about 0.12% of the recirculating flow for the K-31 tower. By 1984, total drift losses for all ORGDP towers are expected to amount to about 4 liters/sec. This drift will contain about 9 mg/liter of Cr^{6+}.

Most of the drift deposition was found to be within about 400 m of the towers. Figure 2.11 is a graphical representative of the chromium concentration found in the soil around the K-33 tower. Similar graphs for zinc and chromium are shown in Figs. 2.12 and 2.13 respectively. As the two figures show, vegetation 1750 m from the tower was found to contain zinc and chromium at levels significantly above background.

The study of the cooling tower's gaseous plumes (steam) revealed that typical plume height is about 100 to 200 m and downwind reach is about 100 to 200 m. The maximum downwind extension was observed to be about 600 m. These plumes initiated cloud development only about 10% of the time.

In addition to cloud development, the evaporative losses from the cooling towers could increase the frequency of fogging in the immediate vicinity of the plant. Based on observation and the use of analytical models,[4] it was concluded that fogging will occur for no more than 300 additional hours during a year, and that this fog will not be observed at a distance greater than 3 km from the towers.

Radioactive waste systems

Enrichment, maintenance, decontamination, development, and testing activities at ORGDP release minimal quantities of low-level radioactive materials to the environment. Since the primary function of the plant is the enrichment of uranium in the U-235 isotope, the vast majority of this material consists of U-238 and U-235, with much smaller quantities of radionuclides received in the past in production reactor returns.

Airborne radioactive wastes. Airborne radioactive release sources include the diffusion purge cascade, the uranium decontamination and recovery facility, the diffusion pilot plant, and a few small development operations. The methods used to maintain as-low-as-practicable emissions from these facilities vary with the particular source. For example, uranium particulates such as those emitted by the uranium recovery facility are removed by filters, whereas gaseous

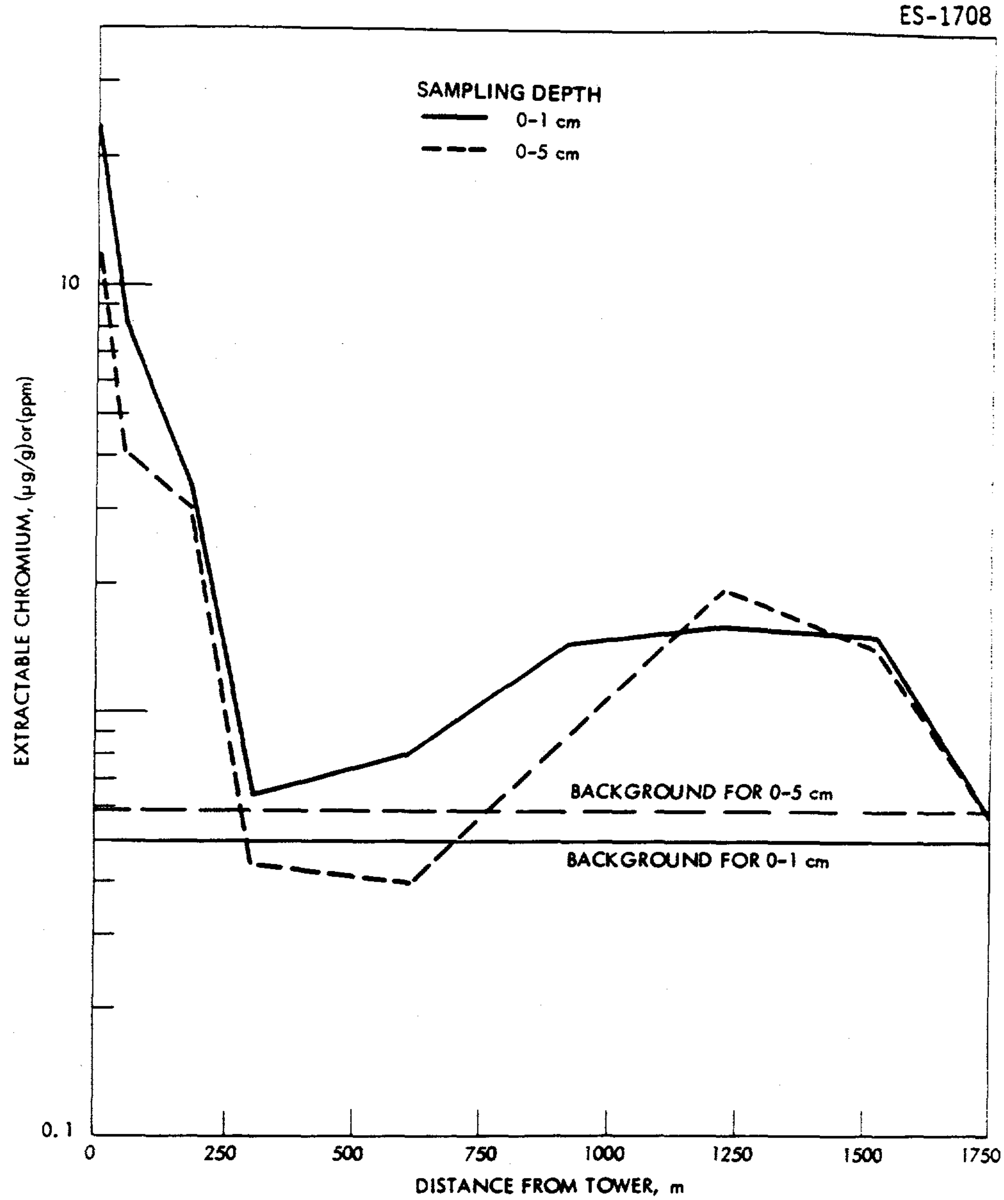

Fig. 2.11. Concentration of extractable chromium in the soil samples as a function of distance from K-33 cooling tower (1973).

uranium compounds are normally removed by chemical traps. One such trap, which is used on the waste stream of the diffusion purge cascade, is the sodium fluoride trap. It provides for the sorption of the UF_6 from the waste stream, and through proper valving and heating, the subsequent desorption of the UF_6, which is returned to the diffusion cascade. Another chemical trap widely used at ORGDP is the alumina trap, employed to remove lower concentrations of uranium, such as those found in the waste streams from maintenance and development facilities. Unlike the sodium fluoride trap, the alumina trap provides for the irreversible sorption of uranium. Therefore, recovery of the uranium collected by these traps requires leaching with nitric acid; this operation is carried out in Building K-1420.

Although reactor returns material is not expected to be introduced into the diffusion plants in the future, chemical traps for its treatment were installed at a time when it was believed that they would be needed. There are no current plans to use recycle fuels. Basically, two types of traps are available for removing unwanted radionuclides. One contains magnesium fluoride, which effectively removes technetium-99, and the other contains cobaltous fluoride,

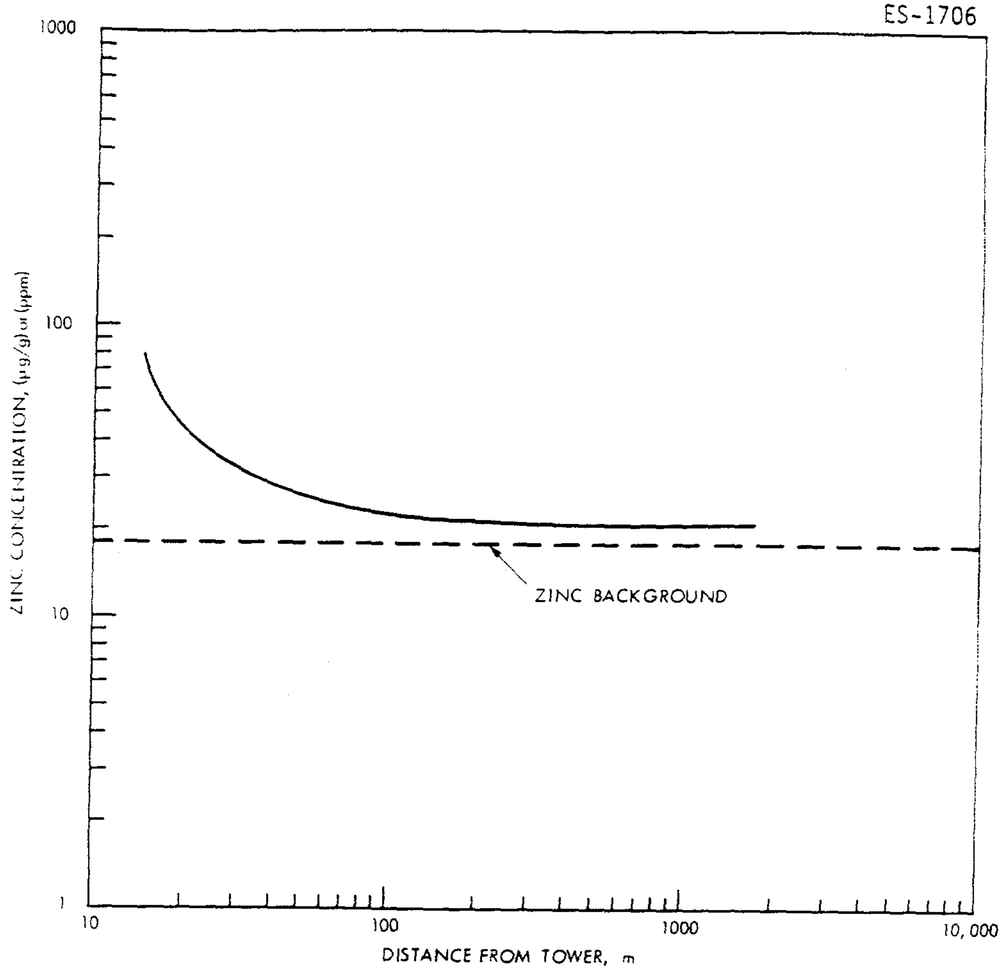

Fig. 2.12. Concentration of zinc in vegetation as a function of distance from K-33 cooling tower (1973).

which removes transuranic elements (plutonium and neptunium). The materials contained in these traps can be given proper disposal, including retrieveable storage.

Table 2.1 lists the total quantity of radionuclides expected to be discharged to the atmosphere from ORGDP in 1984. These airborne releases can be viewed as one hypothetical source at a height of about 12 m (40 ft) and having no excess temperature. Note that the technetium-99 release results from production reactor returns introduced to the cascade in the past. No such material is currently being introduced, nor are there plans to introduce it in the near future.

Liquid radioactive wastes. In 1984, ORGDP will generate five liquid effluent streams containing radionuclides. One stream will be discharged to the Clinch River, three will be discharged to Poplar Creek, which flows into the Clinch River, and one will be collected and transported to the Y-12 Plant for treatment of its nitrate content.

The primary generator of radioactive liquid wastes is the uranium decontamination and recovery facility (K-1420). By 1984, this facility will generate two separate streams which will be treated differently. One stream will consist of decontamination solutions (primarily water) containing uranium and small quantities of technetium-99. This stream will be passed through a treatment system for removing the technetium-99 and will subsequently be discharged to the K-1407-B holding pond, where insoluble uranium compounds will be allowed to settle. The effluent from the K-1407-B pond enters Poplar Creek via the K-1700 discharge (Fig. 2.1). The

ES-1707

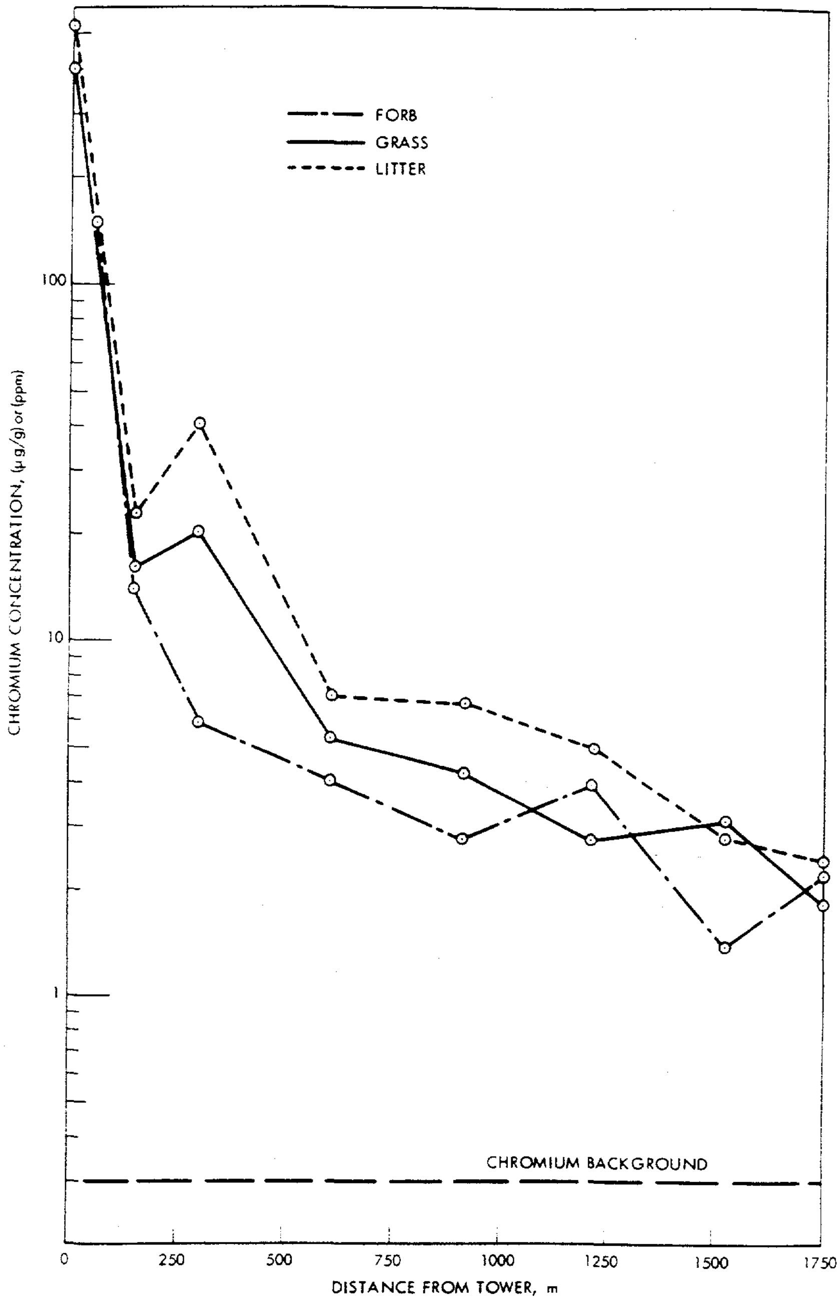

Fig. 2.13. Concentration of chromium in vegetation as a function of distance from K-33 cooling tower (1973).

projected radionuclide content of the K-1700 effluent is given in Table 2.2. The large quantities of technetium-99 released in 1978 (Tables 2.2 and 2.3) are the result of the uprating program. This program requires the removal, cleaning, and repair or replacement of a lot of the process equipment. The cleaning operation necessarily generates wastes, one of which is technetium-99. When this program is completed, the amount of technetium released will be reduced to the values shown in the tables. Technetium traps currently are in storage, awaiting final disposal.

The second radioactive waste stream generated by the K-1'20 facility is the raffinate from the solvent extraction step used in the recovery operation. This waste, which contains high concentrations of nitric acid, will be neutralized and transported to the Y-12 Plant where the

Table 2.1. Airborne radioactive wastes discharged from ORGDP (1984 operation)[a]

Radionuclide	Maximum release rate (Ci/year)
Tc-99	2.0E−6[b]
U-238	9.0E−5
U-236	9.0E−7
U-235	1.7E−5
U-234	5.5E−4

[a] For current (1978) operation, release rates are essentially the same as shown here for 1984.
[b] Read as 2.0×10^{-6}.

Table 2.2. Radionuclides discharged in the K-1700 effluent (1984 operation)[a]

Radionuclide	Maximum release rate (Ci/year)
Tc-99	3.0
U-238	1.3E−1[b]
U-236	3.0E−3
U-235	9.0E−3
U-234	1.9E−1

[a] For current (1978) operation, release rates are essentially the same as shown here for 1984, with the exception of Tc-99, which is 10.0 Ci per year.
[b] Read as 1.3×10^{-1}.

Table 2.3. Radionuclides transported to the Y-12 denitrification facility via the uranium recovery raffinate stream (1984 operation)[a]

Radionuclide	Maximum rate of transport (Ci/year)
Tc-99	2.8
U-238	1.1E−3[b]
U-236	1.4E−3
U-235	2.4E−4
U-234	5.7E−3

[a] For current (1978) operation, release rates are essentially the same as shown here for 1984, with the exception of Tc-99, which is 8.9 Ci per year.
[b] Read as 1.1×10^{-3}.

nitrates will be biodegraded to nitrogen and oxygen. The sludge waste generated by denitrification will be stored in lagoons on the Y-12 site. The radionuclides in this stream in 1984 are listed in Table 2.3. The Y-12 facilities will be described in the forthcoming Y-12 EIA.

The ORGDP sewage plant effluent contains small quantities of radionuclides discharged from the laundry facility. A list of these is given in Table 2.4.

Table 2.4. Radionuclides discharged from the K-1203 sewage plant effluent (1984 operation)[a]

Radionuclide	Maximum release rate (Ci/year)
Tc-99	4.7E−2[b]
U-238	1.5E−5
U-236	1.9E−6
U-235	3.1E−6
U-234	7.3E−5

[a]For current (1978) operation, release rates are essentially the same as shown here for 1984.
[b]Read as 4.7×10^{-2}.

The effluent from the K-1007-B holding pond currently contains small quantities of materials believed to have been transported to the pond by surface runoff from the old diffusion purge cascade area. These materials would have been released as airborne particulates from that area and would have subsequently settled to the ground in the general area of the release. Since a new purge cascade containing new abatement equipment has recently been installed, the airborne releases from this operation have been significantly reduced. Therefore, the radionuclide content of the K-1007-B pond effluent should be reduced to insignificance by 1984.

The K-901-A holding pond effluent (Fig. 2.1) currently contains small quantities of radionuclides that were discharged to the pond from a cylinder disposal operation conducted in the past. Generally, this operation consisted of the controlled puncturing of old cylinders deemed to be unsafe to handle otherwise and the subsequent submersion of the cylinders in the pond to reduce airborne releases. After the cylinder pressure equalized, it was removed from the pond. In the course of this operation, some radionuclides were released to the pond and are continuing to be discharged at a very slow rate to the Clinch River. The projected release rates for these materials in 1984 are listed in Table 2.5.

Table 2.5. Radionuclides discharged from the K-901-A pond effluent (1984 operation)[a]

Radionuclide	Maximum release rate (Ci/year)
Tc-99	3.0E−2[b]
U-238	4.5E−5
U-236	5.0E−5
U-235	3.0E−4
U-234	5.0E−3

[a]For current (1978) operation, release rates are essentially the same as shown here for 1984.
[b]Read as 3.0×10^{-2}.

Solid radioactive wastes. The ORGDP generates solid radioactive wastes by (1) discarding radioactively contaminated scrap paper, wood, trapping media, etc., (2) discarding radioactive process equipment, and (3) removing radionuclides from liquid and airborne releases. Currently, all scrap metal contaminated with radionculides is stored above ground in anticipation of smelting. Sludges generated by settling and scrubbing operations are stored in the three primary holding ponds (K-1007-B, K-1407-B, and K-901-A) and the K-1407-C retention basin. Future plans call for these sludges to be chemically "fixed" by mixing with a concrete-type compound that hardens and greatly reduces leaching and then to be buried. Low-level wastes such as cleaning rags, scrap paper, and trapping media currently are transported to the Y-12 radioactive-waste burial ground. In the past, such materials were buried at the ORGDP site in the contaminated burial ground; it contains about 14 Ci of low-level uranium and thorium. This area (Fig. 2.1) was determined to be geologically unsuitable in 1975, and the burial activity was transferred to the Y-12 site.

The disposal of classified solid wastes, both radioactive and nonradioactive, is handled onsite, within the confines of the ORGDP security fence. The current burial ground, which was opened in the early 1970s, has about 22 acres available for use. It is located between Buildings K-1037 and K-1414, on the eastern extremity of the ORGDP site. This particular location (above the water table) was chosen because its underlying geology, which is Conasauga shale, is more acceptable than any other area immediately available. As of June 1978, this area contained only about 0.1 Ci of low-level uranium waste. The waste is considered nonhazardous and therefore not covered by the Resource Conservation and Recovery Act (RCRA).

Prior to the construction of the new classified burial ground, such wastes were deposited in an area located just north of Building K-1303 and west of the K-1407-B holding pond (Fig. 2.1). This area, due to the presence of surface water, was also deemed unsuitable. No records of its radioactivity are available. However, the monitoring of a small surface spring that passes through the grounds has not detected any radionuclides.

Chemical waste systems

In addition to radioactive wastes, ORGDP also discharges small quantities of nonradioactive chemical wastes. These materials are generated by the diffusion process as well as the several auxiliary operations of the plant. The following discussion describes these wastes.

Airborne chemical wastes. Although ORGDP discharges several different chemical wastes to the atmosphere through over 100 airborne exhausts, only six different constituents are released in significant quantities. These include sulfur dioxide, oxides of nitrogen, fluorides (including chlorine trifluoride), uranium, fluorocarbons, and particulates. The primary sources of these discharges are as follows:

1. Sulfur dioxide — steam plant
2. Oxides of nitrogen — steam plant and uranium decontamination and recovery facility
3. Fluorides — diffusion purge cascade, fluorine plant, equipment treatment facilities, diffusion pilot plant, and various development facilities
4. Uranium — diffusion purge cascade and uranium decontamination and recovery facility
5. Fluorocarbons — diffusion process cooling leaks
6. Particulates — steam plant, uranium decontamination and recovery facility, and various development operations

Since the quantities of materials discharged to the atmosphere from most of the ORGDP facilities are relatively small, no quantitative description of each is presented. However, to facilitate the environmental assessment of these discharges, they have been categorized according to origin and reported as two hypothetical effluents emanating from approximately the center of the plant. One effluent represents the discharges from the seven steam plant boilers, and the other represents the combined emissions of all process and support facilities.

The steam plant (described in Sect. 2.2.3.2) has an equivalent stack height of about 170 ft. The exit gas temperature is about 350°F. Data pertaining to 1984 airborne emissions from this facility are presented in Table 2.6.

Table 2.6. Gaseous effluents from the 1984 ORGDP steam plant[a]

	Release data		
	g/year (av)	g/sec (av)	g/sec (max)
Particulates	5.2E7[b]	1.6	6.1
SO_2	3.2E9	100	240
NO_x	4.3E8	14	37
HF	4.6E6	0.15	0.34

[a]For current (1978) operation, release rates are essentially the same as shown here for 1984.

[b]Read as 5.2×10^7.

The hypothetical effluent representing the combined emissions of the process and support facilities is characterized as a ground source having no excess temperature (temperature greater than the ambient air temperature). Since several of the effluents included in this representation are discharged only intermittently, short-term as well as continuous release rates are listed for 1984 in Table 2.7.

Table 2.7. Release data for the ORGDP hypothetical gaseous effluent representing process and support facilities in 1984[a]

	Total quantity released (g/year)	Release rates (g/sec)		
		Continuous operation	40-hr duration per week	1-hr duration per month
HF	9.0E5[b]	1.0E−3[c]	7.9E−2	5.0E−1
NO_x	13E5	None	14E−2	12E−1
Uranium	140	3.2E−6	2.7E−5	2.9E−5
Particulates	3.8E5	None	1.5E−1	1.5E−1
SO_2	1.3E5	None	4.3E−2	4.3E−2

[a]Data for current (1978) operation are essentially the same as shown here for 1984, except for HF: The total quantity released is 9.8E5 g per year, and the release rate for continuous operation is 1.1E−3 g per second.

[b]Read as 9.0×10^5.

[c]Read as 1.0×10^{-3}.

Liquid chemical wastes. Small quantities of chemical wastes are discharged to Poplar Creek and the Clinch River via six major liquid effluents. A description of each is presented below.

The K-1700 pond discharges into Poplar Creek at a point about 150 m (500 ft) downstream of Blair Bridge (Fig. 2.1). The primary contributors to this effluent are the K-1420 decontamination and recovery facility, the K-1413 development facility, the K-1501 steam plant, the K-1401 metals cleaning facility, the K-1302 nitrogen production facility, and surface runoff from the northeastern region of the plant, including that from the coal storage area. The average rate of flow of this discharge is about 3100 liters/min (820 gpm). Pertinent data on the quality of the K-1700 effluent are given in Table 2.8.

The second liquid chemical effluent from ORGDP is discharged from the K-1410 nickel-plating facility (Fig. 2.1). It consists of a 300-ml/sec (5-gpm) flow of rinse water. Before entering Poplar Creek, the effluent flows through an equalization pit where the pH is adjusted. The 10,000-gal pit is equipped with a continuous pH monitoring system which automatically stops discharge to Poplar Creek when the solution pH is not within the 6.0 to 9.0 range. Pertinent water quality data for the K-1410 discharge are presented in Table 2.9.

Table 2.8. Pertinent water quality data for the K-1700 pond effluent (1984 operation)

Data for current (1978) operation, if different from 1984, are shown in parentheses

	Average background concentration (mg/liter)[a]	Average concentration in discharge (mg/liter)	Maximum monthly concentration in discharge (mg/liter)	Applicable standard or guideline (mg/liter)
(pH	8.0	6.6–7.8 (6.0–9.0)	7.8 (9.0)	6.0–9.0[b])
COD	6.8	22	32	
Aluminum	0.75	0.5	1.0	1.0[b]
Arsenic	<0.01[c]	<0.01	<0.01	1.0[d]
Cadmium	<0.005	<0.005	<0.005	0.01[d]
Chromium (total)	0.005	0.02 (0.03)	0.04 (0.05)	0.05[b]
Copper	0.015	0.02 (0.04)	0.09	1.0[d]
Cyanide	0.001	0.004	0.007	0.03[d]
Fluoride	<0.10	0.91	1.3	20.0[d]
Lead	0.02	0.02	0.04	0.1[d]
Manganese	0.04	0.19	0.32	10.0[d]
Mercury	<0.0009	0.002	0.004	0.005[d]
Nickel	0.009	0.28	1.86	3.0[d]
Nitrate	3.7	10 (49)	15 (88)	90.0[b]
Sulfate	37.5	140	500	1400.0[d]
Zinc	0.03	0.14	1.2	2.0[d]
Suspended solids	10.1[e]	19[e]	56[e]	30.0[b,e]
Dissolved solids	187.3	420 (600)	790 (900)	
Dissolved oxygen	7.5–13.0	7–11	11	
Betz Polynodic 562[f]		7.1	10	
Betz 35A[f]		1.8	2.5	

[a]Background concentrations are determined from samples collected in 1977 from the Clinch River above ORGDP.
[b]Current National Pollutant Discharge Elimination System (NPDES) permit limit for the K-1700 pond effluent.
[c]The symbol "<" indicates that concentrations are below detectable limits, which are listed.
[d]Tennessee Department of Public Health, *Guidelines for Effluent Criteria for Sewage and Industrial Wastewater*, 1973.
[e]NPDES limits and reported data are for times of no precipitation only.
[f]Industrial corrosion inhibitors.

The K-1131 UF_6 feed operation discharges steam condensate to Poplar Creek at a point just north of the facility (Fig. 2.1). Under normal operating conditions, the effluent consists of only condensed steam at about 38°C (100°F). Since the volume of this discharge is small (less than 5 gpm), the excess heat it releases is dissipated within an extremely small area of Poplar Creek.

The K-1007-B holding pond, which is located at the southern extremity of the ORGDP site, discharges into Poplar Creek at about Poplar Creek Mile 1.3. It is primarily an outlet for surface runoff from the southern area of the plant site and a flow equalizer for small quantities of routine caustic and acidic laboratory wastes. The rate of discharge is about 100 liters/sec (1600 gpm). Pertinent water quality data for this pond are given in Table 2.10.

The K-901-A holding pond, which serves primarily as a collection basin for the recirculating water system's caustic treatment sludge, empties directly into the Clinch River at a rate of about 90 liters/sec (1400 gpm). By 1984, this pond will be preceded by two additional ponds to provide for removal of most of the settleable solids and for pH adjustment of the liquid overflow. Table 2.11 gives data pertaining to the K-901-A pond effluent in 1984.

The ORGDP sanitary water treatment facility (K-1515, see Fig. 2.1) also generates a liquid chemical waste effluent. This waste, which consists of solids coagulated, settled, and filtered from the plant's potable water, is discharged to a large holding pond which provides for removal of the solids prior to release to the Clinch River at a rate of about 145 gpm. Pertinent data on the quality of the effluent from this pond are listed in Table 2.12.

Table 2.9. Pertinent water quality data for the K-1410 nickel-plating facility effluent (1984 operation)

Data for current (1978) operation, if different from 1984, are shown in parentheses

	Average background concentration (mg/liter)[a]	Average concentration in discharge (mg/liter)	Maximum monthly concentration in discharge (mg/liter)	Applicable standard or guideline (mg/liter)
(pH	8.0	6.5–8.5 (6.0–9.0)	9.0	6.0–9.0[b])
COD	6.8	30	70	
Aluminum	0.75	6.3	40	250.0[c]
Iron	0.65	5.0	8.5	10.0[c]
Chromium (total)	0.005	0.02	0.05	3.0[c]
Copper	0.015	0.15	0.50	1.0[c]
Cyanide	0.001	<0.001[d]	0.001	≤0.001[b]
Lead	0.02	0.05	0.07	0.1[c]
Manganese	0.04	0.50	2.6	10.0[c]
Nickel	0.009	1.5 (15)	2.5 (25)	3.0[c]
Nitrate	3.7	3.5	16	
Sulfate	37.5	230	1200	1400[c]
Zinc	0.03	0.29	0.85	2.0[c]
Suspended solids	10.1[e]	16[e]	30[e]	40.0[c,e]
Dissolved solids	187.3	1800 (2000)	3700 (4000)	
Dissolved oxygen	7.5–13.0	7–13	13	

[a] Background concentrations are determined from samples collected in 1977 from the Clinch River above ORGDP.
[b] *Current NPDES permit limit for the K-1410 facility effluent.*
[c] Tennessee Department of Public Health, *Guidelines for Effluent Criteria for Sewage and Industrial Wastewater*, 1973.
[d] The symbol "<" indicates that concentrations are below detectable limits, which are listed.
[e] NPDES limits and reported data are for times of no precipitation only.

Sanitary waste systems

Two separate systems are used at ORGDP to treat and discharge sanitary (domestic sewage) wastes. Both have recently been upgraded to provide secondary treatment that meets all existing Environmental Protection Agency (EPA) liquid discharge standards. The main sewage plant meets EPA discharge standards most of the time.[5] For example, the percentage of measurements in compliance was >95% for ammonia, BOD, dissolved oxygen, fecal coliform bacteria, and pH; suspended solids were 89% in compliance; and settleable solids, 67%. The primary reason for the noncompliances is occasional hydraulic overloading resulting from infiltration and intrusion of surface runoff following heavy rainfall. The sewage system piping will be repaired as part of an FY 1980 line-item project. The small sewage treatment plant is currently on standby due to underloading. An aboveground sand filter is used for the small maintenance and security forces currently at the powerhouse.

The larger of the two systems (K-1203) serves the main plant site and treats a flow of about 620,000 gpd. The treatment facility consists of an activated-sludge extended-aeration process which also provides for postaeration and chlorination. Table 2.13 gives relevant data pertaining to the K-1203 effluent.

The small sewage treatment plant serving the powerhouse area (Fig. 2.1) also uses the activated-sludge process for biodegrading wastes. Pertinent data relating to the 5-gpm effluent from this facility are presented in Table 2.14.

Storm waste systems

In addition to the liquid waste systems dedicated to the disposal of heat, radioactivity, and chemical wastes, ORGDP also has an extensive network of underground piping to remove surface runoff following rainfall. None of the more than 50 discharge locations is routinely treated or monitored. The primary constituent of each is, of course, suspended soil particles.

Table 2.10. Pertinent water quality data for the K-1007-B pond effluent (1984 operation)[a]

	Average background concentration (mg/liter)[b]	Average concentration in discharge (mg/liter)	Maximum monthly concentration in discharge (mg/liter)	Applicable standard or guideline (mg/liter)
(pH	8.0	8.5	9.0	6.0–9.0[c])
BOD_5	2.0	4.2	7.4	30.0[d]
COD	6.8	15	23	20.0[c]
Arsenic	<0.01[e]	0.01	0.03	1.0[d]
Cadmium	<0.005	0.005	0.005	0.01[d]
Chromium (total)	0.005	0.03	0.05	0.05[c]
Copper	0.015	0.02	0.05	1.0[d]
Cyanide	0.001	0.001	0.004	0.03[d]
Fluoride	<0.10	0.33	0.94	1.0[c]
Lead	0.02	0.01	0.03	0.10[d]
Manganese	0.04	0.08	0.40	10.0[d]
Mercury	<0.0009	0.002	0.004	0.005[d]
Nickel	0.009	0.095	0.800	3.0[d]
Nitrate	3.7	1.8	13	
Sulfate	37.5	150	610	1400[d]
Zinc	0.03	0.03	0.10	2.0[d]
Suspended solids	10.1[f]	15[f]	23[f]	30.0[c,f]
Dissolved solids	187.3	310	820	
Dissolved oxygen	7.5–13.0	5–12	12.4	≥5.0[c]

[a]Data for current (1978) operation are essentially the same as shown here for 1984.
[b]Background concentrations are determined from samples collected in 1977 from the Clinch River above ORGDP.
[c]Current NPDES permit limits for the K-1007-B pond effluent.
[d]Tennessee Department of Public Health, *Guidelines for Effluent Criteria for Sewage and Industrial Wastewater*, 1973.
[e]The symbol "<" indicates that concentrations are below detectable limits, which are listed.
[f]NPDES limits and reported data are for times of no precipitation only.

Effluent and environmental monitoring

The ORGDP monitoring effort has, for administrative convenience, been divided into two related categories — the effluent monitoring program and the environmental monitoring program. The effluent monitoring program, as its name implies, is designed to provide quantitative information on liquid and gaseous effluents. Not only does this information provide a basis for determining compliance with applicable regulations, it also allows an evaluation of the adequacy and effectiveness of treatment systems. The environmental monitoring program provides similar quantitative information on the environment into which the plant effluents are discharged. The media routinely monitored are surface streams, surface-stream bottom sediments, subsurface waters, soil, vegetation, and the ambient air. A more detailed description of of these two programs is presented below.

Effluent monitoring. The effluent monitoring program for liquid discharges is designed, for the most part, around the requirements of the EPA-formulated National Pollutant Discharge Elimination System (NPDES). To fulfill these requirements, sampling stations are provided for nine discharges. Five of these stations [K-1407-B, K-1700, K-1203, K-901-A, and K-1007-B (see Fig. 2.14)] are equipped to continuously monitor pH, temperature, dissolved oxygen, and specific conductance. Each of these parameters for each station is currently recorded on strip charts located in the plant's central control room. Each is equipped with an audible alarm to indicate deviation from normal operation. By 1984, these data will be transmitted directly to a central computer facility where they will be stored and reduced to usable information. The same five stations are also equipped with continuous-flow proportional composite samplers which are operated for a 24-hr period once each week. The individual samples are then composited monthly and analyzed for about 20 parameters indicative of water quality.

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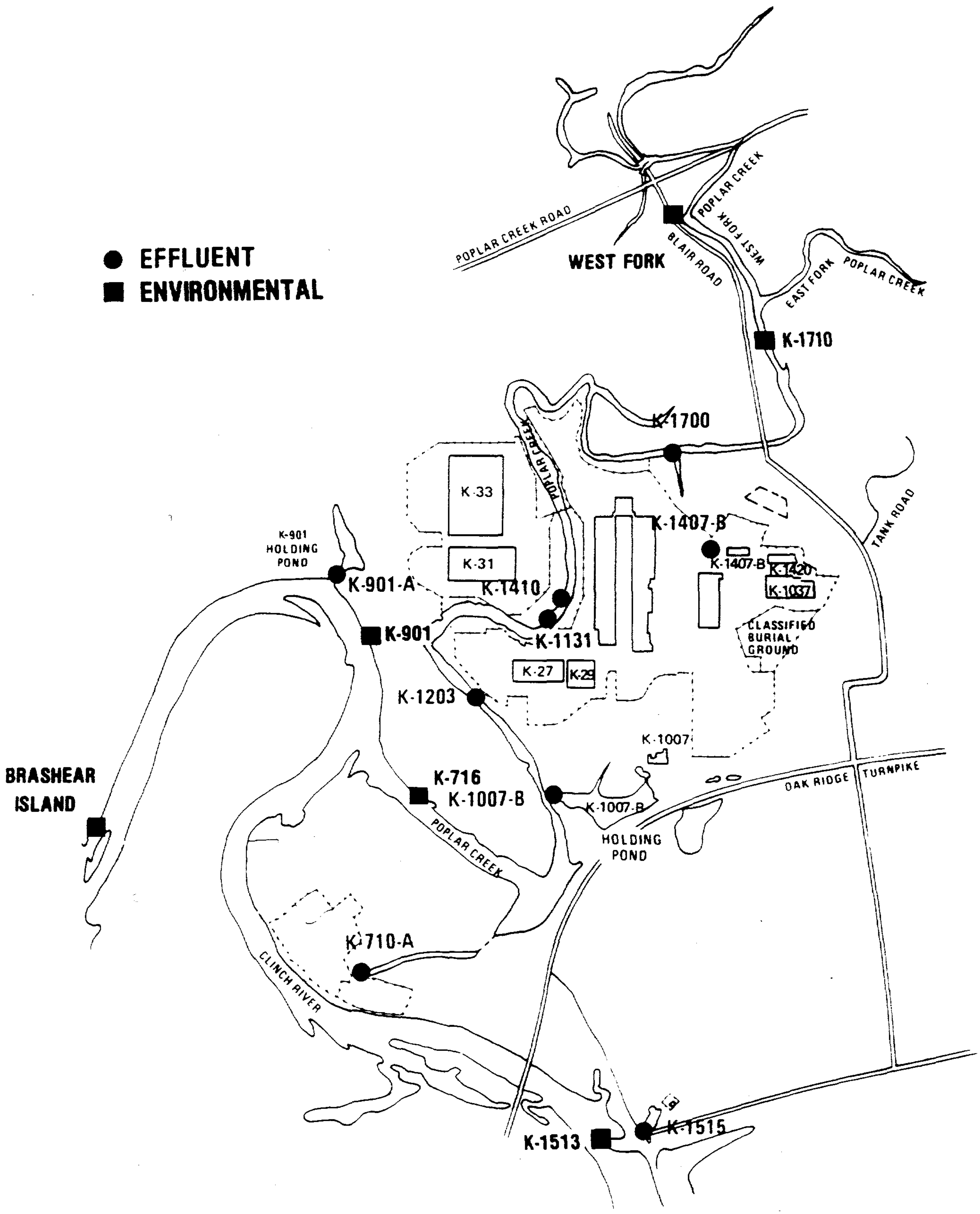

Fig. 2.14. Water monitoring stations for ORGDP.

Table 2.11. **Pertinent water quality data for the K-901-A pond effluent (1984 operation)[a]**

	Average background concentration (mg/liter)[b]	Average concentration in discharge (mg/liter)	Maximum monthly concentration in discharge (mg/liter)	Applicable standard or guideline (mg/liter)
(pH	8.0	8.5	10.0	6.0–10.0[c])
BOD_5	2.0	6.1	9.1	30.0[d]
COD	6.8	20	39	
Arsenic	<0.01[e]	0.01	0.03	1.0[d]
Cadmium	<0.005	0.005	0.005	0.01[d]
Chromium (total)	0.005	0.03	0.05	0.05[c]
Copper	0.015	0.03	0.12	1.0[d]
Cyanide	0.001	0.004	0.007	0.03[d]
Fluoride	<0.10	0.22	0.30	1.0[c]
Lead	0.02	0.02	0.03	0.1[d]
Manganese	0.04	0.06	0.40	10.0[d]
Mercury	<0.0009	0.001	0.002	0.005[d]
Nickel	0.009	0.040	0.150	3.0[d]
Nitrate	3.7	7.1	33	
Sulfate	37.5	1300	2100	1400[d]
Zinc	0.03	0.09	0.50	2.0[d]
Suspended solids	10.1[f]	18[f]	41[f]	30.0[c,f]
Dissolved solids	187.3	930	1600	
Dissolved oxygen	7.5–13.0	10–15	15	

[a]Data for current (1978) operation are essentially the same as shown here for 1984, except for the pH of the discharge: The average pH is 8.0, and the maximum monthly pH is 9.0.

[b]Background concentrations are determined from samples collected in 1977 from the Clinch River above ORGDP.

[c]Current NPDES permit limits for the K-901-A pond effluent.

[d]Tennessee Department of Public Health, *Guidelines for Effluent Criteria for Sewage and Industrial Wastewater*, 1973.

[e]The symbol "<" indicates that concentrations are below detectable limits, which are listed.

[f]NPDES limits and reported data are for times of no precipitation only.

The four liquid effluent sampling stations not equipped with continuous samplers [K-1410, K-1131, K-710-A, and K-1515 (Fig. 2.14)] are grab sampled. The weekly grab samples are also composited monthly and analyzed for about 20 water quality parameters.

The primary airborne effluents that are routinely monitored are those from the diffusion purge cascade, the fluorine production plant, the diffusion pilot plant, the steam production facility, the barrier manufacturing facility, the uranium decontamination and recovery facility, and the various development facilities, including those associated with the gas centrifuge program. The only effluent continuously monitored is that from the diffusion purge cascade: An isokinetic sample is withdrawn from the stack gas and analyzed daily for uranium and fluoride content. Once a month, a sample is also analyzed for technetium-99, plutonium, and neptunium-237.

Methods of sample collection and analysis differ, depending on the parameters being monitored and the nature of the effluent in which they are contained. For example, uranium- and fluoride-containing samples normally are collected by water or caustic bubblers, whereas organic vapors are collected on some type of sorbent such as activated carbon.

Environmental monitoring. As mentioned previously, ORGDP's environmental monitoring program is aimed at providing representative data relating to the impact of the plant's effluents. The impact of the liquid effluents is evaluated by monitoring area surface waters (Poplar Creek and Clinch River) and the surface-water bottom sediments.

Poplar Creek is monitored at three locations (Fig. 2.14). Two of these stations (K-1710 and K-716) are equipped with continuous composite samplers which are operated for one 24-hr period each week. The individual weekly samples are then composited monthly and analyzed for about 20 parameters. In addition to the composite samplers, these two Poplar Creek stations are also instrumented to continuously measure and record pH, temperature, specific conductance, and dissolved oxygen. Monthly grab samples from Poplar Creek are taken at a third location labeled "West Fork" in Fig. 2.14.

Table 2.12. Pertinent water quality data for the K-1515 pond effluent (1984 operation)[a]

	Average background concentration (mg/liter)[b]	Average concentration in discharge (mg/liter)	Maximum monthly concentration in discharge (mg/liter)	Applicable standard or guideline (mg/liter)
(pH	8.0	7.5	8.3	6.0–9.0[c])
BOD_5	2.0	1.8	2.0	30.0[d]
COD	6.8	8.3	19	
Aluminum	0.75	1.6	17	250.0[e]
Chloride	5.8	5.9	7.5	
Fluoride	<0.10[f]	0.20	0.3	20.0[d]
Silicon	3.0	3.4	5.8	
Iron	0.65	1.7	2.4	10.0[d]
Sulfate	37.5	100	320	1400.0[e]
Manganese	0.04	0.14	0.74	10.0[d]
Dissolved solids	187.3	180	250	
Suspended solids	10.1[c]	6.7[c]	12[c]	30.0[c,e]
Dissolved oxygen	7.5–13.0	8–13	13	

[a]Data for current (1978) operation are essentially the same as shown here for 1984, except for dissolved solids: The maximum monthly concentration is 180 mg/liter.

[b]Background concentrations are determined from samples collected in 1977 from the Clinch River above ORGDP.

[c]NPDES limits and reported data are for periods of no precipitation only.

[d]Tennessee Department of Public Health, *Guidelines for Effluent Criteria for Sewage and Industrial Wastewater,* 1973.

[e]Current NPDES permit limit for the K-1515 pond effluent.

[f]The symbol "<" indicates that the concentration is less than the limit of detection, which is shown.

Table 2.13. Pertinent water quality data for the large (K-1203) ORGDP sewage treatment facility (1984 operation)[a]

	Average monthly concentration (mg/liter)	Applicable EPA standards[b] (mg/liter)
BOD_5	5–10	15
Suspended solids	5–15	30
Ammonia nitrogen	0.4	5
Dissolved oxygen	⩾5.0	⩾5.0
Chlorine residual	0.5–2.0	0.5–2.0
Total phosphorus	0.90	
Potassium	2.8	
Nitrates	3.8	
Dissolved solids	190	
(Flow, gpm	420)	
(pH	6.8–8.0	6.0–9.0)

[a]Data for current (1978) operation are essentially the same as shown here for 1984, except for BOD_5, which is 5–15 mg/liter, and suspended solids, 5–20 mg/liter.

[b]Current NPDES limits for the K-1203 effluent, monthly average.

Table 2.14. Pertinent water quality data for the small (K-710) ORGDP sewage treatment facility (1984 operation)[a]

	Average monthly concentration (mg/liter)	Applicable EPA standards[b] (mg/liter)
BOD_5	6.3	30.0
Suspended solids	9.1	30.0
Ammonia nitrogen	0.20	
Dissolved oxygen	⩾5.0	
Chlorine residual	0.5–2.0	0.5–2.0
Total phosphorus	1.5	
Potassium	3.9	
Nitrates	2.1	
Dissolved solids	250	
(Flow, gpm	5.0)	
(pH	7.3–8.0	6.0–9.0)

[a]Data for current (1978) operation are essentially the same as those shown here for 1984.

[b]Current NPDES limits for the K-710 effluent, monthly average.

The Clinch River is monitored at three locations (K-1513, K-901, and just above Brashear Island). The K-1513 and K-901 stations are equipped with continuous composite samplers, which are operated for one 24-hr period each week, whereas the Brashear Island site affords only a monthly grab sample. All Clinch River samples are composited and analyzed monthly.

Bottom sediments in the Clinch River and Poplar Creek are sampled semiannually and analyzed primarily for metals, including uranium, plutonium, neptunium, technetium, mercury, lead, copper, and aluminum. The locations of these 20 sampling stations are depicted in Fig. 2.15.

The environmental impact of ORGDP airborne effluents is evaluated by monitoring the ambient air, terrestrial vegetation, and soil at locations nearby and relatively far from the plant. The primary pollutants of concern are gaseous fluorides, SO_2, NO_X, and total particulates, including fly ash and uranium. Locations of the ambient-air sampling stations are shown in Fig. 2.16. Soil and terrestrial vegetation samples are collected semiannually at the sites shown in Figs. 2.17 and 2.18 and are analyzed for essentially the same parameters as is ambient air. Impacts are discussed in Sect. 5.

The monitoring of the effects of land disposal of solid wastes will be accomplished with several deep wells (180 to 300 ft) located within and adjacent to the areas receiving such wastes. The data from this program will, as that collected by all the environmental and effluent monitoring programs, be computerized for storage and reduction to a usable form.

2.2.4 Transportation

The transportation of solid UF_6, other chemicals and materials, and personnel is an integral part of the operation of ORGDP. The UF_6 shipments, which are by rail and truck, include those between ORGDP and other government-owned gaseous diffusion plants, those from UF_6 production plants to ORGDP, and those from ORGDP to fuel-processing facilities. All these shipments contain solid UF_6 at subatmospheric pressure and all are regulated by both the U.S. Department of Energy (DOE) and the U.S. Department of Transportation (DOT). Under these regulations, all UF_6 shipping containers must meet ANSI N1471 specifications. In addition, all enriched material of more than 1.0% uranium-235 and/or that exceeds 3.0 Ci (such as the shipments of enriched material to private enrichment customers) must be shipped in steel cylinders enclosed in DOE- and DOT-approved packages. These protective packages, which enclose 10- or 2.5-ton cylinders of UF_6, must meet stringent specifications pertaining to their resistance to fire,

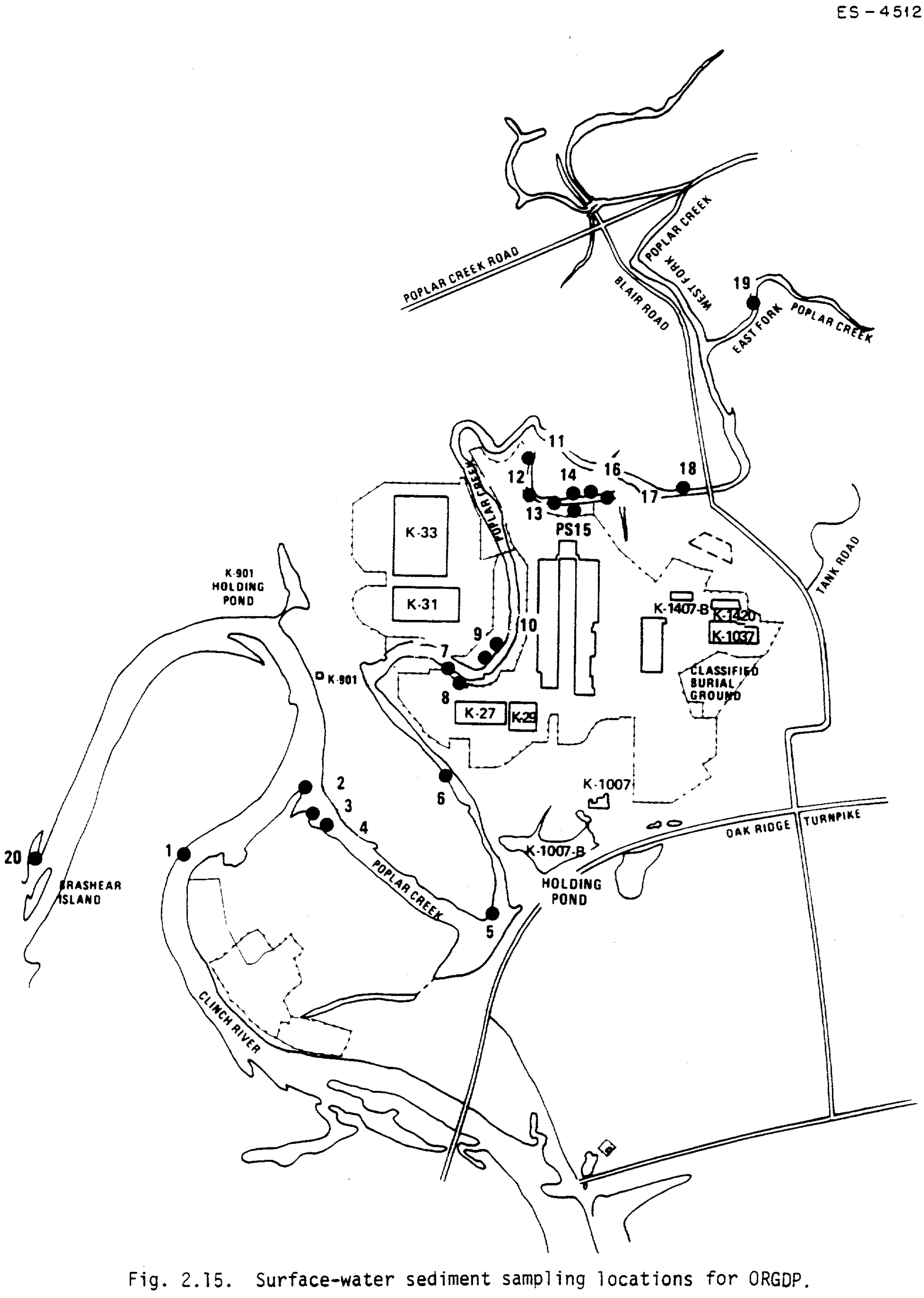

Fig. 2.15. Surface-water sediment sampling locations for ORGDP.

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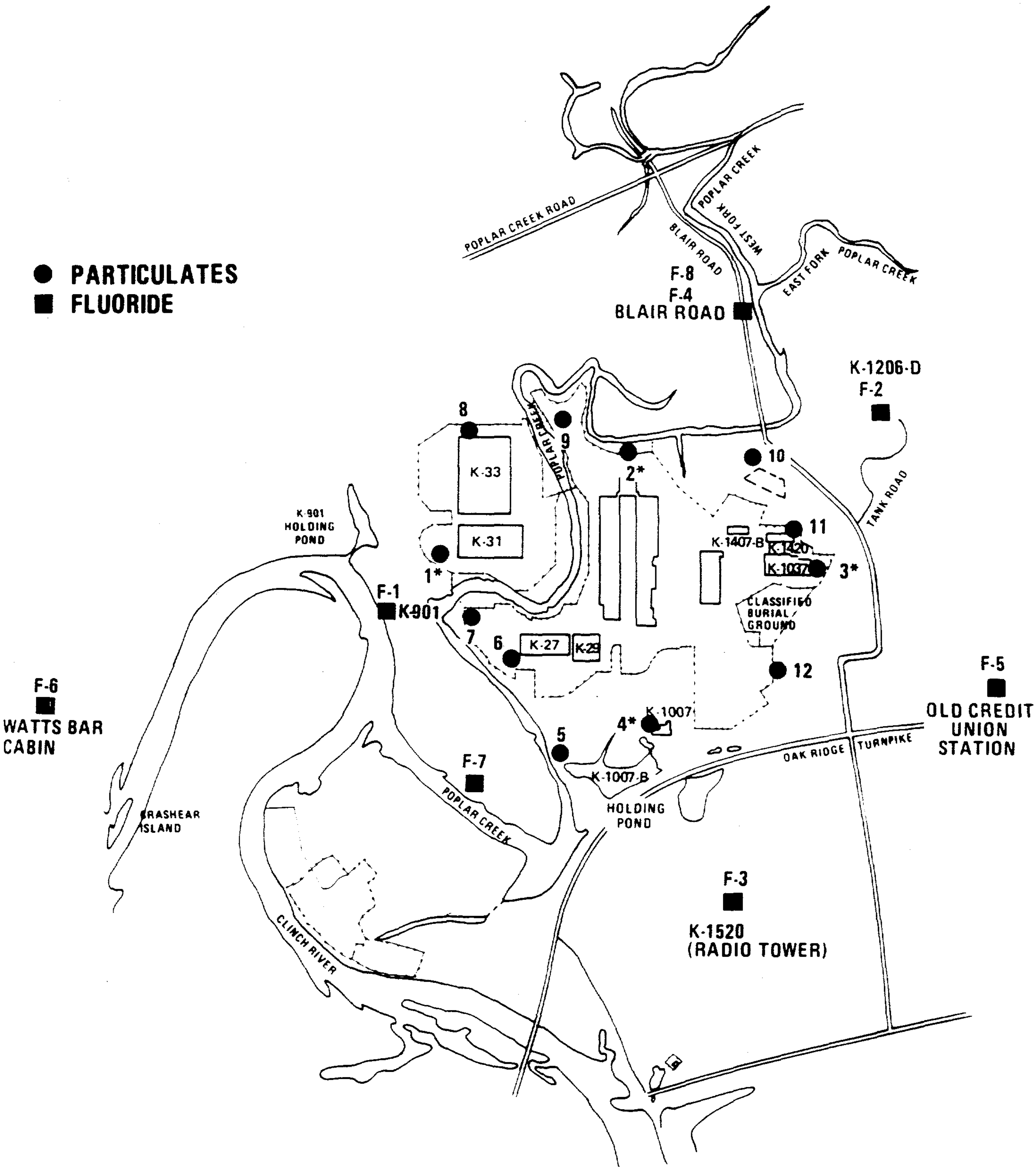

*TIMER-OPERATED SAMPLES (24-hr SAMPLE TAKEN EVERY 8TH DAY)

Fig. 2.16. Ambient-air particulate and fluoride sampling locations for ORGDP.

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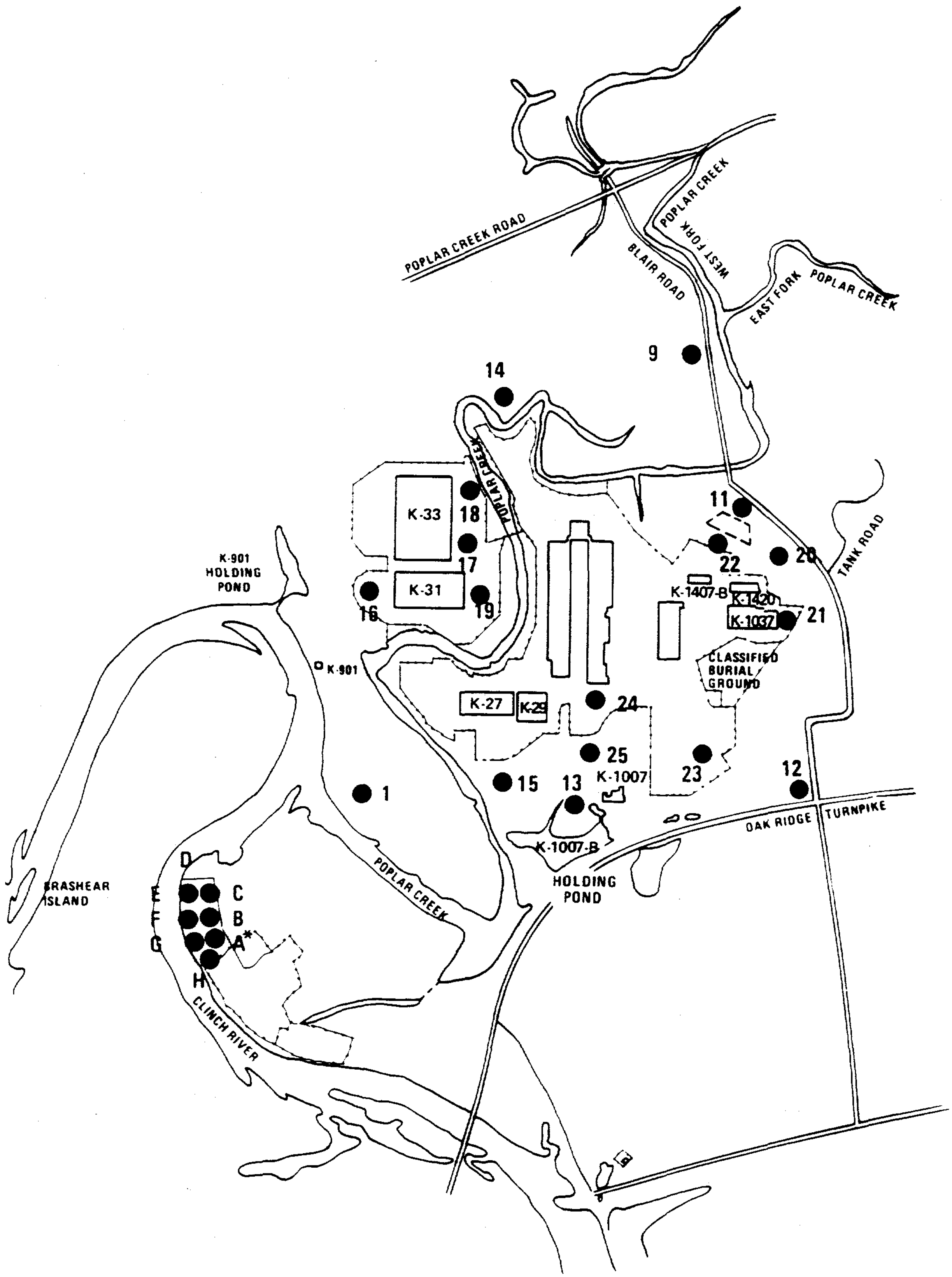

*POWERHOUSE SCRAP YARD SOIL SAMPLE LOCATIONS A–H TAKEN MONTHLY

Fig. 2.17. Soil and vegetation sampling stations located near ORGDP.

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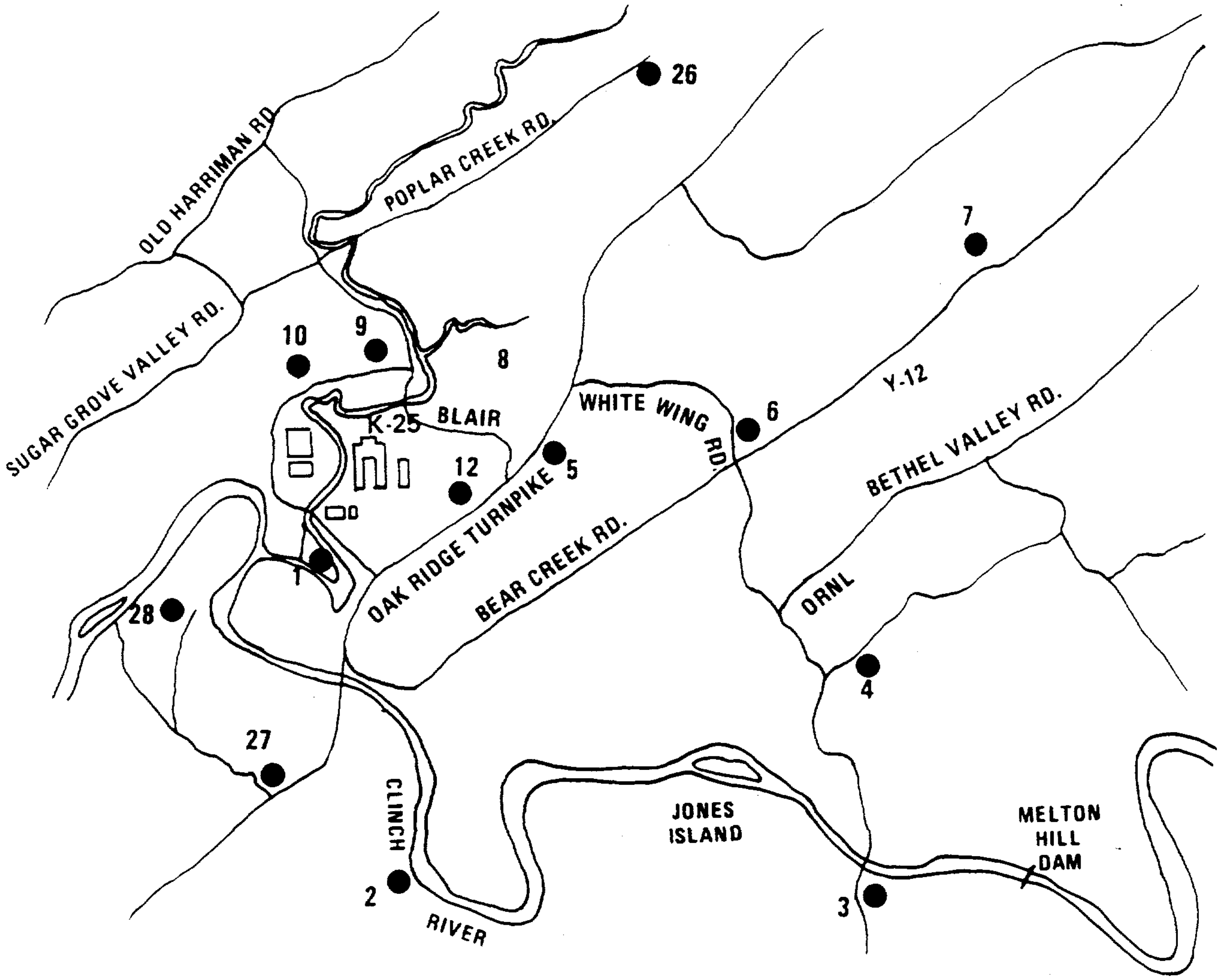

Fig. 2.18. Soil and vegetation sampling stations located away from ORGDP.

water, and a 30-ft drop, as outlined in 10 CFR Part 71, Appendix B. Extensive effort has been expended on the design and development of the package tie-down apparatus to ensure that the package remains intact within the carrier.

Shipments of UF_6 that contain less than 1.0% uranium-235 and have a total radioactivity of less than 3.0 Ci do not require protective packages.

Uranium feed material to ORGDP is of two different types: (1) normal feed and (2) slightly enriched uranium-235 from the Paducah Gaseous Diffusion Plant (PGDP). Table 2.15 lists the locations and distances from the Oak Ridge area to the other domestic facilities that handle UF_6 before and after enrichment.

During FY 1984, 75% of the normal feed is expected to be delivered in 14-ton cylinders and 25% in 10-ton cylinders. A single 14-ton cylinder or two 10-ton cylinders will be transported on each truck. Four 10- and 14-ton cylinders will be shipped on each rail car. About 17% of all UF_6 shipments will be by rail. All product material is and will be shipped in 2.5-ton cylinders (5 cylinders per truck); each cylinder will be enclosed within a protective package.

Table 2.15. Distances from ORGDP to Paducah Gaseous Diffusion Plant, UF_6 production plants, and processors of uranium fuel materials

	Distance to ORGDP (miles)
PGDP	340
UF_6 production plants	
Allied Chemical Metropolis, Ill.	275[a]
Kerr-McGee Sequoyah, Okla.	800[a]
Fuel processors	
Babcock and Wilcox (Numec subsidiary) Apollo, Pa.	450[b]
General Electric Co. Wilmington, N.C.	400[b]
Gulf-United Nuclear Fuels Hematite, Mo.	400[b]
Jersey Nuclear Co. Richland, Wash.	3000[b]
Kerr-McGee Corp. Oklahoma City, Okla.	800[b]
Nuclear Fuel Services, Inc. Erwin, Tenn.	150[b]
Westinghouse Electric Corp. Columbia, S.C.	250[b]

[a]U.S. Atomic Energy Commission, *Environmental Survey of the Uranium Fuel Cycle,* WASH-1248, April 1974, p. D-8.
[b]Ref. *a*, p. D-9.

In addition to vehicles required for shipping UF_6, ORGDP maintains a vehicular fleet for personnel use. If fleet size and annual fuel consumption are assumed to stay in proportion to plant population (about 6400 in 1978 vs 4500 predicted for 1984), there will be, in 1984, about 400 vehicles in the fleet which will require about 308,000 gal of gasoline and diesel fuel.

2.2.5 Accidents

The preceding descriptions of ORGDP are based on normal operating activities. Other potentials for environmental impacts lie within the probabilities of accidental releases.[1] Since ORGDP uses extreme caution in all its operations, these probabilities are remote. However, certain occurrences, such as natural phenomena (earthquakes, tornadoes, etc.) and/or equipment failures, could result in accidental releases. The following discussions characterize six types of potential accidents. A detailed discussion of the impacts of these accidents, including radiation doses to the public, is given in Sect. 5.5.

2.2.5.1 Criticality accidents

The ORGDP processes fissile materials which, under certain circumstances, could produce an accidental critical mass reaction. However, the probability of a criticality accident that could result in serious consequences to personnel is extremely remote because of design features, detailed operating procedures, administrative controls, and regular nuclear safety surveys. Controls that aid in the prevention of a criticality incident are listed below.

1. When any equipment or process is developed and the design begun, nuclear safety personnel review all drawings and procedures to be certain that the equipment or process meets the nuclear safety criteria required to prevent criticality accidents.

2. A request is made to nuclear safety personnel for an evaluation. After review, a nuclear safety clearance is issued. All limitations on handling are stated on this form.

3. At least quarterly, the staff of the ORGDP Nuclear Criticality Safety Department conducts an audit of all plant areas that handle, process, or store enriched uranium. This procedure meets the requirements set by the DOE.[6]

4. A survey of all cascade equipment is made semiannually.

A criticality incident in a low-enrichment diffusion plant is highly improbable. Detailed evaluations of cascade equipment under normal and contingency operating conditions have demonstrated the inherent nuclear safety of the cascade. If the integrity of the diffusion equipment is not breached, criticality cannot occur in unmoderated, low-enriched UF_6 (up to 5% uranium-235). Criticality is possible in the moderated state (water is considered to be the most significant of the nuclear-moderating and ordinary reflecting materials generally available) if the necessary quantity of fissile material is accumulated in a nuclearly favorable configuration.

Mostly, uranium is handled in the cascade in the gas phase at low enrichment conditions where criticality incidents are least likely to occur. Operations in which uranium-bearing solutions and solids are processed at uranium-235 enrichments above 1% require equipment design and operating controls for a geometry, mass, or volume that meets nuclear safety criteria.

If a criticality incident occurred at low enrichment, it would be a thermal system, that is, one in which the fission is induced primarily by neutrons in substantial thermal equilibrium with a moderating material and the fissile material. The fission yield from a typical thermal system accident is only about 10^{17} fissions, which is equivalent to an energy release of about 1 kWhr. In the event of a nuclear incident, most of the materials, if releases occurred, would be expected to be contained within the equipment or building, resulting in only nuisance contamination and cleanup in the immediate vicinity.

2.2.5.2 Diffusion process accidents

Large-scale enrichment of uranium by the gaseous diffusion process necessarily involves the transfer of large quantities of UF_6, primarily in the gaseous state. Also used are significant quantities of lubricating oil and refrigerant (Freon-114). Since the systems using these materials contain specially designed and operated equipment to help prevent accidental releases, the probability of significant losses is extremely remote. The following examples of possible releases thus represent the worst-case, lowest-probability type of incidents.

Should the pressure-relief devices of the coolant system fail and subsequently allow a rupture, as much as 20,000 lb (9000 kg) of Freon-114 could be released into the process building. Due to the normally warm temperatures within the building, essentially all this material would probably vaporize and be lost to the atmosphere before it could be recovered.

A similar failure of the lubricating oil system could result in 22,500 gal (85,000 liters) being released into the process building. Any material that escaped the building could be recovered from oil collection pits which will be installed on all process-area storm drain lines by 1984.

Process equipment operating at pressures above atmospheric will be subject to extensive releases if failure occurs. To lessen the probability of such releases, several precautions have been incorporated in the equipment design; for example, high-quality, inspected welding joints are used in all equipment operating above atmospheric pressure, out-leakage detection equipment is used in above-atmospheric-pressure cells, and vibration detection equipment is used for predicting compressor failure. However, assuming that several of these systems fail to prevent or contain a release, the following incident is presented as an illustration of what could occur.

The failure of a bearing in a compressor causes a hole about 37 in.^{2} (240 cm^2) to be torn around the shaft. Two possible modes of failure could then occur. In the first, the compressor would deblade, causing only normal system pressure to force the out-leakage of UF_6.

In the second, the compressor continues to operate for about 3 min before being stopped manually. This would keep the pressure of the system up to the normal cell operating pressure, thus increasing the amount of UF_6 released. In the first instance, it is calculated that 5.8 lb (2.6 kg) would be released in less than 1 sec before the release is stopped when the system equilibrates at atmospheric pressure. In the second instance, a total of 3000 lb (1400 kg) of UF_6 could be released to the building (where it would quickly hydrolyze to form UO_2F_2 and HF). The air in the building is changed by the ventilation system about every 6 min. Therefore, every 3 min, about one-half of the material contained in the building is exhausted to the outside air. The amount of HF released in this maximum credible incident is 680 lb (310 kg). Assuming an assay of 1% uranium-235, the isotope release (in curies) after one air change of 6 min is as follows:

$$\text{U-234} = 2.76 \times 10^{-1}$$

$$\text{U-235} = 1.45 \times 10^{-2}$$

$$\text{U-236} = 8.6 \times 10^{-4}$$

$$\text{U-238} = 2.2 \times 10^{-1}$$

(Note: After one air change, a maximum of 1500 lb (680 kg) of uranium has been exhausted to the atmosphere, assuming that 22% of the UO_2F_2 settles out into the building.)

The impacts of this type of accident are discussed in Sect. 5.5.2.

2.2.5.3 Centrifuge process accidents

Due to the nature of the operation of a gas centrifuge enrichment facility such as the Component Test Facility (CTF), UF_6 is the only material present that could adversely affect the environment. Furthermore, because of the low-throughput characteristics of the process, the total quantity of UF_6 in the CTF is much less than that in a diffusion facility of similar size. Therefore, the worst credible release resulting from a centrifuge process accident would create a much less severe impact than the worst credible release from a diffusion process accident. Because the CTF is presently the centrifuge pilot plant at ORGDP, the remainder of this section deals only with accidents associated with this facility. Cylinder handling and transportation accidents that would be common to both the centrifuge and diffusion processes are described in the following sections.

Because a centrifuge cascade operates below atmospheric pressure, a UF_6 pipeline rupture would initially result in air entering the cascade. After pressure equilibrium is reached, releases of small quantities of UF_6 could occur due to reverberations and back diffusion. In addition, the reaction of the UF_6 with moisture in the in-leaking air could produce solid UO_2F_2 and gaseous HF which could be released.

On October 20, 1973, three ORGDP centrifuge machines broke loose from their mounts, and the process lines to each were exposed to atmospheric pressure. The total amount of UF_6 lost during this incident was less than 0.25 lb (115 g).

Based on this information, a CTF accident involving the failure of 100 machines exposed to atmosphere would release no more than 10 lb (4.5 kg) of UF_6. It is extremely difficult to speculate on the time intervals for such hypothetical releases other than to indicate that intervals of minutes, rather than seconds or hours, would be more likely. An example of 100 centrifuges releasing UF_6 for 5 min would provide a maximum release rate of about 0.03 lb/sec (13 g/sec) of UO_2F_2 and about 0.007 lb/sec (3 g/sec) of HF. Note that these rates represent releases into buildings. The amounts that would escape to the atmosphere, while currently unquantifiable, would be much less.

2.2.5.4 UF_6-handling accidents

The majority of UF_6 used outside the diffusion cascade is handled in 2.5-, 10-, and 14-ton steel cylinders. About 20 of these cylinders are handled each day, but by 1984 the rate is expected to be about 50 per day. The remainder of this section deals with possible UF_6-cylinder-handling accidents and the releases that might occur. The greatest potential for a UF_6 release exists where cylinders of the liquid are handled routinely. Areas where this is done include the K-1131 feed and tails withdrawal facility, the K-413 product withdrawal facility, and the K-1423 toll enrichment facility.

Descriptions of the two accidents that would result in maximum credible releases of UF_6 are presented in cases 1 and 2 below. In each case, release of the contents of a 14-ton cylinder of 3.2% uranium-235 material, a typical product assay, is hypothesized. Although 3.2% uranium-235 material normally is not contained in 14-ton cylinders, government regulations do not prohibit it. Therefore, such containment is assumed for a worst-case accident analysis.

Other more probable, smaller-scale handling accidents would likely occur inside a building and would include leaks from cylinder valves and sampling apparatus. Release from these types of accidents would be slow enough to allow emergency containment actions to be taken by ORGDP personnel. Such actions would include closing building doors and windows, removing heat from the leaking cylinders, plugging or patching the leak, and introducing steam into the room to produce UO_2F_2 and HF. The UO_2F_2 should settle within the building, from which it could be removed by a vacuum system. The HF would react with the building and equipment, and a small quantity would be released to the atmosphere.

Case 1

A 14-ton cylinder of liquid UF_6 hydraulically ruptures while being heated in an enclosed autoclave or steam hood. Solid UF_6 or UO_2F_2 (resulting from the reaction of the UF_6 with H_2O) probably would, at some point, block the path of flow from the cylinder to Poplar Creek, thus preventing loss of the complete contents of the cylinder. However, since the amount that would be released from such an occurrence is unquantifiable, this particular analysis assumes the worst case, that is, that the entire contents of the cylinder (about 27,560 lb of liquid UF_6) would flow through the condensate line to Poplar Creek in about 20 min. (Note that some of the autoclaves and all of the steam hoods used at ORGDP are not of the high-pressure type and thus might not contain all the UF_6 released from the cylinder. An atmospheric release is covered in case 2.) Upon reaching the creek, the UF_6 would react with the water to form UO_2F_2 and HF. Resulting concentrations of uranium and HF in Poplar Creek during extremely low-flow conditions and during normal flow conditions are presented for this worst case in Table 2.16; resulting concentrations of uranium and HF in the Clinch River, assuming complete mixing, are also listed for low-flow and normal flow conditions. The MPC_w (maximum permissible concentration for public drinking water) is 3×10^{-7} Ci/liter for the most restrictive uranium isotope and the most sensitive organ.[7] The concentrations in Poplar Creek for low flow and normal flow and in the Clinch River for low flow (Table 2.16) exceed this value.

The impacts of this type of accident are discussed in Sect. 5.5.4.

Table 2.16. Stream concentrations of uranium[a] and fluorides resulting from potential worst-case UF_6-handling-accident case 1

	Stream flow (cfs)	Fluoride as HF (mg/liter)	Uranium (mg/liter)	Concentration of radioactivity (Ci/liter)
Poplar Creek				
Low flow	25	3300	9800	1.8E–5[b]
Normal flow	220	370	1100	2.1E–6
Clinch River				
Low flow	600	140	410	7.7E–7
Normal flow	6000	14	41	7.7E–8

[a] Isotopic content of uranium (in Ci): U-234, 10.24; U-235, 0.57; U-236, 0.05; U-238, 2.67; total, 13.53.

[b] Read as 1.8×10^{-5}.

Case 2

A 14-ton cylinder of liquid UF_6 (at about 220°F) is dropped while being handled in the storage area outside Building K-1423 (toll enrichment facility). Although these cylinders do have metal skirts protecting their valves and are always moved with the valves in the "up" (12 o'clock) position, the dropping could result in the valve being severed while in the "down" (6 o'clock) position. If this should happen, the entire contents of the cylinder (27,560 lb of UF_6) would be released onto the concrete-paved storage area within about 15 min. During this 15-min period, about 16,000 lb (7300 kg) of UF_6 would vaporize as the liquid solidified. The remaining solid UF_6 (at a temperature of about 133°F) would then slowly cool to ambient temperature (about 70°F) through the vaporization of an additional 140 lb (64 kg).

The reaction of the vaporized UF_6 with the moisture in the atmosphere would produce UO_2F_2 and HF. Assuming the rate of the UF_6 vaporization to be constant over the 15-min release period, UO_2F_2 would be released at a rate of about 15.6 lb/sec (7 kg/sec), and HF would be released at a rate of about 4.0 lb/sec (1.8 kg/sec). The isotopic content of the material lost from the cylinder would be the same as for case 1. The environmental impacts of this incident are discussed in Sect. 5.5.4.

2.2.5.5 UF_6-transportation accidents

Uranium hexafluoride, like many other chemical compounds, has hazardous properties that must be considered during its transportation. These properties include the radioactivity and toxicity of the uranium and the toxicity of the fluoride. Because the UF_6 is transported in thick-walled steel cylinders, neither of these properties presents a problem during normal transportation. However, a release to the environment resulting from a transportation accident would present the possibility for environmental damage. The remainder of this section deals with potential releases to the environment resulting from transportation accidents, as well as precautionary measures taken to prevent such accidents.

The DOE is involved in the transportation of UF_6 to and from its gaseous diffusion plants and several private industrial firms. However, only the shipments from Paducah Gaseous Diffusion Plant to ORGDP are the direct responsibility of ORGDP. These shipments include transport by rail car of low-specific-activity (natural and depleted UF_6) material, as well as fissile (enriched UF_6) material. All such shipments contain solid UF_6 at subatmospheric pressure and all are regulated by both DOE and DOT. Under these regulations, all shipping containers are required to meet ANSI N1471 specifications (see Sect. 2.2.4). An accident involving the release of UF_6 from a cylinder enclosed within these protective packages is much less probable than one involving an unpackaged cylinder.

Materials containing less than 1.0% uranium-235 and having a total radioactivity of less than 3.0 Ci do not require special protective packages for shipping. To estimate the potential environmental damage that could result from a UF_6 transportation accident, three hypothetical cases involving unpackaged 14-ton cylinders are described. In each case, the UF_6 cylinder has a maximum gross weight of 32,760 lb and a tare weight of 5200 lb; the maximum quantity of available UF_6 is thus 27,560 lb.

Case 1

A rail car carrying four unpackaged 14-ton cylinders of natural material (about 0.7% uranium-235) is involved in a severe accident that punctures a 6-in.-diam hole in one of the cylinders (in the void space). A 200-MWt fire results with a temperature of 1475°F, an emissivity of 0.9, and a duration of 1.7 hr. According to statistical analysis,[3] the occurrence probability of this type of accident is about 1.1×10^{-11} per vehicle mile. Considering the fact that unprotected cylinder shipments of UF_6, now made exclusively by rail between Paducah Gaseous Diffusion Plant and ORGDP, require about 90,000 vehicle miles per year, one accident of this type would be expected to occur every 1.0×10^6 years. An accident that results in a fire of less than 30 min would be expected to occur once every 1.1×10^4 years.

When the fire begins, conduction and convection should be the controlling mechanisms for transferring heat from the cylinder wall to the solid UF_6. Because UF_6 is a very poor conductor of heat, its surface temperature would quickly rise to about 140°F, at which temperature its vapor pressure is about 20 psia. At this point the solid UF_6 would sublime to the gas phase and subsequently flow out of the cylinder. As the peripheral UF_6 sublimed, a gap between the solid UF_6 and the wall of the cylinder would result. Radiant heat transfer would then become the controlling mechanism for transferring heat to the solid UF_6. Based on this consideration, the predicted rate of the UF_6 release would increase exponentially until it peaked at a cylinder temperature of about 1300° to 1400°F. During the course of the 1.7-hr fire, about 22,000 lb (10,000 kg) of UF_6 (about 80% of the contents of the cylinder) would be released. As this material flowed from the cylinder, it would react with the moisture in the atmosphere to form UO_2F_2 and HF. A summary of the pertinent characteristics of this release is presented in Table 2.17 on a per-cylinder basis. (Of course, four times as much material would be released should all four cylinders be punctured.)

Maximum individual radiation and HF doses resulting from this accident (computed for one cylinder) are presented in Sect. 5.5.5.

Table 2.17. Summary of pertinent release characteristics (per cylinder) for transportation accident case 1

Material released	22,000 lb (10,000 kg) of UF_6
Material dissipated to the environment	19,000 lb (8800 kg) of UO_2F_2 5,000 lb (2300 kg) of HF
Release duration	1.7 hr
Release rates	UO_2F_2, 3.2 lb/sec (1400 g/sec) HF, 0.8 lb/sec (370 g/sec)
Temperature of release	1475°F
Isotopic content	U-234, 1.80 Ci U-235, 0.10 Ci U-238, 2.19 Ci

Case 2

A rail car carrying four unpackaged 14-ton cylinders of low-specific-activity (natural) material is involved in a severe accident that does not result in the puncture of a cylinder. However, as in case 1, a 1.7-hr fire of 1475°F engulfs the cylinder. According to statistical analyses,[8] an accident of this type could be expected to occur once every 1.6×10^6 years.

As heat was added to the UF_6 in the closed cylinder, the temperature would rise to about 145°F, at which point the UF_6 would begin to melt; vapor pressure would be about 22 psia. If heat were added slowly, as in a steam chest, the UF_6 solid and liquid would remain at about 145°F until all the solid had melted. However, since the fire associated with this accident supplies heat at a rapid rate, the surface of the UF_6, which is a poor conductor of heat, should quickly rise to a temperature much higher than 145°F. Vapor pressure in the cylinder would then increase correspondingly.

Although sufficient information is not available to predict the detailed behavior of the UF_6 under these accident conditions, a series of fire tests conducted on small UF_6 cylinders at ORGDP provides enough information to formulate an adequate description of the cylinder failure. In these tests, the cylinders were exposed to flames from a pool of diesel fuel burning at about 1500°F. The largest cylinder tested, 8 in. ID x 3/16 in. thick x 48 in. long and made of nickel, exploded 8.5 min after the fire was started. Using the yield strengths of the small nickel test cylinder and the large steel cylinder, the internal pressure required for rupture was determined to be about the same for each cylinder. Therefore, by realizing that the amount of UF_6 that must be evaporated in each cylinder to reach this rupture pressure is inversely proportional to the void volume within the cylinder, and by assuming that the rate of heat transfer into the two cylinders is the same per unit of surface area, the time required for the large cylinder to fail was determined to be about 48 min. Whereas the uncertainty of the assumptions used in this analysis would surely preclude any inference regarding the exact time required for the large steel cylinder to fail, the 1.7-hr fire associated with this particular accident would probably result in a cylinder failure.

The release resulting from the cylinder failure would be characterized by an initial explosion of UF_6, followed by a diminishing rate of release.

If the resistance to heat transfer into the cylinder and its contents were high, large temperature gradients would develop and the failure would occur, due to the high vapor pressure, a relatively short time after the fire began. Since only a small quantity of UF_6 would have melted, the initial release should be relatively small. On the other hand, if good heat transfer into the UF_6 developed, due to the convective movement of the liquid UF_6 in the cylinder, a large quantity of the contents might melt before the failure occurred. In this case, a relatively large initial release would result. In either case, the contents of the cylinder should be expelled explosively, causing the residual solid UF_6 to break up and thus provide a large area for reaction with available moisture. As in the previous accident case, the reaction products would be UO_2F_2 and HF.

Because the release rates of these two compounds depend on the quantity of UF_6 that remains in the solid phase (as described above), two source terms for this accident are presented in Tables 2.18 and 2.19. Table 2.18 represents the case in which a large portion (90%) of the UF_6 remained in the solid form, and Table 2.19 represents the case in which a small portion (20%) remained in the solid form. As in the previous case, the values given are on a per-cylinder basis. The environmental impacts of this accident are discussed in Sect. 5.5.5.

Table 2.18. Summary of pertinent release characteristics (per cylinder) associated with the early release described for transportation accident case 2 (90% remaining in solid form)

Total amount of material released	27,600 lb (12,500 kg) of UF_6
Material dissipated to the environment	Instantaneous release of 10% (2760 lb) of gaseous UF_6 that hydrolyzes to form 2400 lb (1100 kg) of UO_2F_2 and 630 lb (290 kg) of HF. The remaining 25,000 lb (11,000 kg) of solid UF_6 is thrown out of the influence of the fire and thus hydrolyzes, over a period of about 4 hr, to produce 22,000 lb (9900 kg) of UO_2F_2 and 5600 lb (2600 kg) of HF
Release rates	
Instantaneous	UO_2F_2, 2400 lb (1100 kg)
	HF, 630 lb (290 kg)
For next 4 hr	UO_2F_2, 1.5 lb/sec (690 g/sec) that remains on ground
	HF, 0.4 lb/sec (180 g/sec) to atmosphere
Isotopic content	
Airborne	U-234, 0.22 Ci
	U-235, 0.01 Ci
	U-238, 0.27 Ci
On ground at accident site	U-234, 2.02 Ci
	U-235, 0.11 Ci
	U-238, 2.47 Ci

Case 3

A rail car carrying four unpackaged 14-ton cylinders of low-specific-activity (natural) material is involved in an accident that results in cylinder puncture. Because impact tests have shown that it is nearly impossible for a cylinder to become separated from the car, both the carrier and the attached cylinders are assumed to fall into a body of water. The reaction of the water with the UF_6 will produce UO_2F_2 and HF which will escape from the cylinder; the time required for the entire contents of the cylinder to enter the stream has been determined to be about 3.0 hr. Insufficient data are available to predict the probability of this type of accident.

The behavior of the UO_2F_2 and HF solution would depend on the characteristics of the receiving body of water. For example, should the cylinder fall into a deep pool within the bed of a lake or reservoir, the high density of the solution combined with a relatively low stream flow could result in retention of the solution in high concentration within the pool, presenting the possibility of removal before significant environmental damage resulted. On the other hand, should the cylinder fall into a relatively fast-flowing stream, the escaping UO_2F_2 and HF would become completely mixed with the stream and could adversely affect the stream for a considerable

Table 2.19. Summary of pertinent release characteristics (per cylinder) associated with the delayed release described for transportation accident case 2 (20% remaining in solid form)

Total amount of material released	27,600 lb (12,500 kg) of UF_6
Material dissipated to the environment	Instantaneous release of 80% (22,000 lb) of gaseous UF_6 that hydrolyzes to form 19,000 lb (8600 kg) of UO_2F_2 and 5000 lb (2800 kg) of HF. The remaining 5500 lb (2300 kg) of solid UF_6 is thrown out of the influence of the fire and thus hydrolyzes, over a period of about 1 hr, to produce 4800 lb (2200 kg) of UO_2F_2 and 1300 lb (590 kg) of HF
Release rates	
Instantaneous	UO_2F_2, 19,000 lb (8600 kg) HF, 5000/lb (2300 kg)
For next 1 hr	UO_2F_2, 1.3 lb/sec (610 g/sec) that remains on ground HF, 0.3 lb/sec (160 g/sec) to atmosphere
Isotopic content	
Airborne	U-234, 1.80 Ci U-235, 0.10 Ci U-238, 2.19 Ci
On ground at accident site	U-234, 0.45 Ci U-235, 0.03 Ci U-238, 0.55 Ci

distance, depending on the amount of added dilution provided by tributaries. Since the latter example is both more severe and more probable, the concentrations of uranium and HF resulting from this case only are listed in Table 2.20 for various stream flows. The MPC_w of 3 x 10^{-7} Ci/liter is not exceeded in this postulated scenario (Table 2.20).

Table 2.20. Stream concentrations of uranium[a] and fluoride (per cylinder) resulting from transportation accident case 3

Stream flow (cfs)	Fluoride concentration as HF (mg/liter)	Uranium concentration (mg/liter)	Total concentration of radioactivity (Ci/liter)
100	95	280	1.7E–7[b]
1,000	9.5	28	1.7E–8
10,000	0.95	2.8	1.7E–9

[a] Isotopic content of uranium (in Ci): U-234, 2.25; U-235, 0.13; U-238, 2.74; total, 5.12.

[b] Read as 1.7 × 10^{-7}.

The environmental and health impacts of this type of accident are discussed in Sect. 5.5.5.

2.2.5.6 Accidental chemical releases

Due to the nature of operations that include various chemical processes, many types of organic, acidic, caustic, and oil-containing materials are used at ORGDP. In many areas, these chemicals are stored in quantities that, if released, could be mitigated locally before significant environmental damage occurred. For example, Building K-1420 (Fig. 2.1) houses several tanks ranging in volume from 100 to 900 gal. These tanks contain various concentrations of sulfuric, hydrochloric, and nitric acids. If the entire contents of one of these tanks were released, the chemical would drain to the K-1407-B holding pond, where a continuous pH monitoring system would automatically stop the discharge from the pond until the pH was adjusted.

There are several large tanks that could affect the pH of Poplar Creek if the entire contents were released. However, the probability for such an occurrence is remote because these tanks are periodically inspected to verify their integrity, and special secondary containment systems have been constructed.

At ORGDP, 99 electrical transformers contain an estimated 127,000 gal of polychlorinated biphenyls (PCB). In addition, about 13,250 capacitors contain an estimated 24,800 gal of PCB. All the capacitors and 95 of the transformers (123,000 gal) are located inside buildings where adequate secondary containment is provided. This containment consists of curbing around all walls and plugged floor drains. The four outside transformers are also provided with special protection and containment systems to prevent releases. By 1984, these four outside transformers will have been replaced by the non-PCB dry types.

Another chemical release that could conceivably occur involves the K-892 cooling towers (Fig. 2.1) used to cool the K-33 process water. The process water includes a corrosion inhibitor containing about 10 ppm of Cr^{6+}. The basin underneath the K-892 cooling towers is above ground, whereas other cooling towers have basins below ground level. Because of the aboveground design, a rupture in the K-892 basin could conceivably allow water containing Cr^{6+} to enter Poplar Creek. The K-892 basin normally contains 12 million gal of water. Four accident cases are hypothesized:

1. Twelve million gallons (45 Ml) of water enters Poplar Creek within a 15-min period when a minimum flow exists in Poplar Creek (5 cfs) and no flow in the Clinch River (Melton Dam flow is 0).

2. Twelve million gallons of water enters Poplar Creek within a 15-min period when an average flow condition exists both in Poplar Creek (165 cfs) and in the Clinch River (4600 cfs).

3. Twelve million gallons of water enters Poplar Creek within a 5-hr period when a minimum flow exists in Poplar Creek (5 cfs) and no flow in the Clinch River.

4. Twelve million gallons of water enters Poplar Creek within a 5-hr period when an average flow condition exists both in Poplar Creek (165 cfs) and in the Clinch River (4600 cfs).

The 15-min and 5-hr periods were arbitrarily chosen to depict a range of concentrations. The essentially no-flow condition that occasionally exists in the Clinch River could conceivably result in a wedge several hundred feet long and several feet thick on the surface of the river; the wedge would consist of undiluted discharge from the warmer Poplar Creek waters. Table 2.21 lists the Cr^{6+} concentrations that would result from these cooling tower accidents.

Table 2.21. Chromium concentrations resulting from hypothetical cooling tower accidents

Case	Concentration in Poplar Creek (ppm of Cr^{6+})	Concentration in Clinch River (ppm of Cr^{6+})	Tennessee Stream Guideline (ppm of Cr^{6+})
1	10	10[a]	0.05
2	9.2	2.7	0.05
3	9.5	9.5[a]	0.05
4	3.5	0.18	0.05

[a] See discussion in text.

The most catastrophic release of a hazardous chemical that could occur at ORGDP would be the release of anhydrous hydrofluoric acid (AHF) from the K-1132 HF tank farm (Fig. 2.1). The storage of 80,000 lb of AHF in each of two storage tanks at K-1132, the storage of up to 5000 lb in each of two smaller (day) tanks at K-1131, and the transfer of AHF through pipes by air pressure have been accomplished safely for more than 20 years. Internal inspection and ultrasonic thickness tests every two years indicate no metal loss from the 5/8-in.-thick steel tank walls.

Anhydrous hydrofluoric acid is a colorless liquid or gas, depending on its temperature, but fine droplets, resulting from condensation of water vapor due to its interaction with HF, make the vapor appear white in the atmosphere. The boiling point is about 67°F at atmospheric pressure. Both the liquid and the gas are very corrosive and can cause severe burns to body tissues.

Since liquid HF is transferred under pressure from the tank car to the storage tank and from the storage tank to cylinders, there is a potential for burns each time the operators make or break connections. Convenient eye baths and safety showers, protective clothing and safety equipment, and trained operators using safe procedures are provided to prevent serious accidents. The design of the piping at K-1132 was modified and the system replaced to further minimize leakage potential. A concrete dike was constructed around the tanks with drainage to an underground tank capable of containing about 80,000 lb of HF. The dike encloses a 119 x 56 ft area.

Assuming that both of the storage tanks ruptured, the entire contents (160,000 lb) would spill into the diked area and flow by gravity to the underground tank. To simulate a worst-case condition, the liquid in the tank is assumed to be at 90°F. Because the boiling point of AHF is 67.1°F, about 8.75% (14,000 lb) of the liquid that spilled would immediately flash or vaporize when subjected to atmospheric pressure. The remaining 146,000 lb of AHF would then flow into the underground tank within about 10 min. Figure 2.19 depicts this release rate with respect to time.

2.2.6 Security

A comprehensive security program is maintained at ORGDP to meet DOE requirements for protecting the valuable enriched uranium, the equipment used for effecting the enrichment, and the technical information related to the enrichment. The basic components of this program are a physical protection system, a nuclear material control system, and an internal personnel control program.

The physical protection program relies primarily on providing multiple barriers between the plant and unauthorized persons. Specific examples include armed guards, physical barriers such as cyclone fencing and steel-plated safes and file cabinets, and sophisticated surveillance systems such as motion detectors and closed-circuit television monitors. Additional provisions include regular inspections of unattended facilities, searches of incoming and outgoing vehicles, random searching of packages, briefcases, etc., and redundant communication systems. The guard force is, of course, specially trained and equipped with the most modern detection and protective equipment.

The nuclear material control program is designed to maintain strict accountability of the uranium received, processed, and disposed of by the plant. This task is accomplished through detailed analysis of feed and product material, effluent streams, and in-process inventories. Appropriate ledgers and registers are carefully kept so that monthly accountability reports reflect an accurate picture of movements, releases, and inventories.

The personnel control program requires that all ORGDP employees possess a security access authorization clearance. Such clearances are granted by DOE after an appropriate investigation has revealed that the individual can be granted access without endangering the common defense and security of the plant. To further enhance the security clearance system, each cleared person is required to wear a plant-issued photographic badge for identification. Before entrance to the plant, a matching cover badge must be obtained from security personnel stationed at the entrance portals.

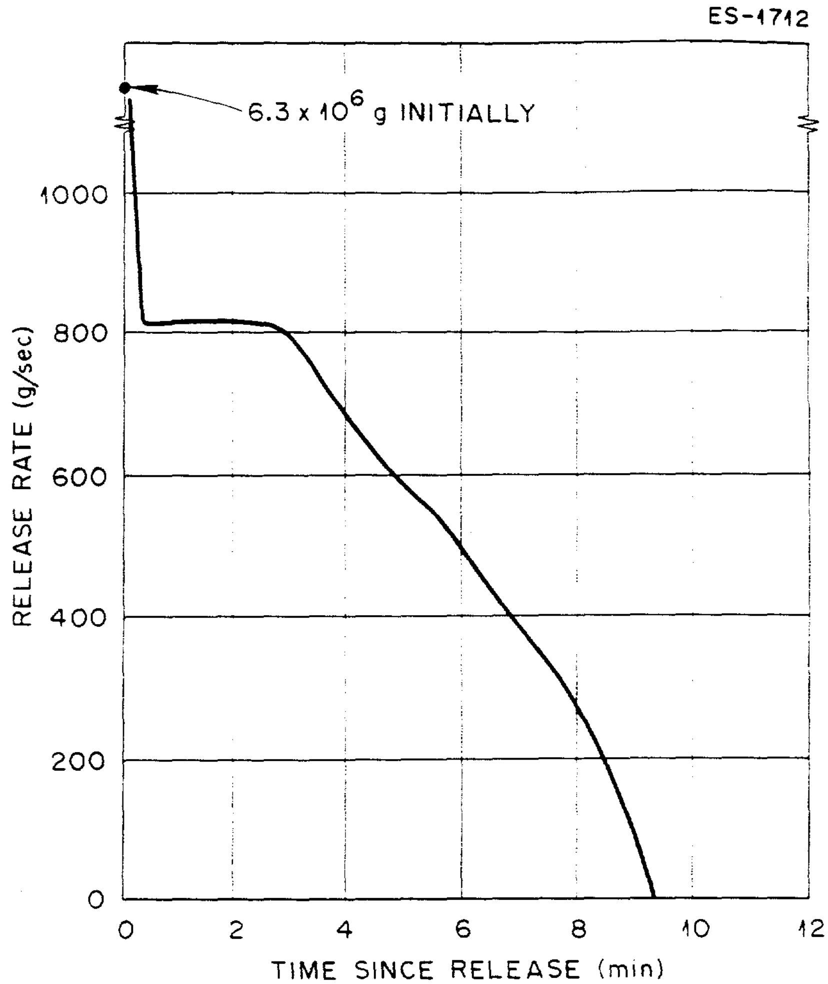

Fig. 2.19. Release rate vs time for an accidental instantaneous release of 72,500 kg HF into diked area.

2.3 POWER-GENERATING FACILITIES

By 1984, ORGDP will require about 2080 MWe of electrical energy. This energy will be supplied by the TVA, which will have a total generating capacity of about 42,618 MWe. Fossil-fuel plants, including both coal-fired and gas turbine units, will provide about 20,306 MWe of this capacity. The remainder will be provided by hydro units (4533 MWe), nuclear plants (16,249 MWe), and a pumped storage unit (1530 MWe). Since the TVA system functions as a single unit, no specific generating plant(s) can be viewed as being dedicated to ORGDP. Therefore, the following descriptions pertain to the general system and not to individual units.

2.3.1 Transmission lines and towers

All transmission lines are constructed per TVA specifications and standards and are either 161 or 500 kV. In addition, several 69-kV subtransmission lines are used by the city of Oak Ridge. By 1984, the total number of miles in the Oak Ridge area will be 55.9 of 500-kV line, 88.3 of 161-kV line, and 14.4 of 69-kV line.

Steel transmission towers for both single- and double-circuit lines are self-supporting, four-legged, and of a flat configuration, with body extensions and variable-length legs to provide height variations to fit the towers to the topography. The standard height of a 500-kV tower is 84 ft, but river crossings, highway crossings, and large angles require special towers. The 500-kV towers in the Oak Ridge area vary in height from 80 to 188 ft. Spacing between the towers also depends on the topography and varies from 800 to 1700 ft.

Steel towers for the 161-kV lines are normally 60 to 90 ft high, and spacing varies from 500 to 1600 ft.

The wood pole structures that support 161-kV circuit lines are usually from 60 to 90 ft high, and spacing varies from 500 to 1200 ft.

2.3.2 Transmission-line corridors

Generally, the cleared widths of the rights-of-way are 75 ft for 69 kV, 100 ft for 161 kV, and 175 ft for 500 kV. In addition, all "danger" trees are cut. A tree is considered a danger tree if, when cut at the ground line, it would fall within 5 ft of a 69- or 161-kV line or within 10 ft of a 500-kV line. Where more than one line occupies the same right-of-way, the width is increased. This situation occurs in areas adjacent to substations and where lines run parallel or are installed on double-circuit towers.

By 1984, the total area in Oak Ridge cleared for transmission-line corridors will be 2721 acres, which includes 130 acres in the Y-12 area, 480 acres for the city of Oak Ridge, and about 400 acres for TVA use. This leaves about 1700 acres for the 161- and 500-kV network serving ORGDP.

Most of the rights-of-way are through wooded areas and along ridges and originally were on government-owned property. The more recent lines from the TVA Bull Run Steam Plant are routed over pasture land in the areas near the Bull Run Plant site. The little agriculture in the Oak Ridge area is an experiment of The University of Tennessee. Clearances over rivers, railroads, and highway crossings are maintained by using special-height towers on either side.

Access roads are not too frequent, but most rights-of-way are suitable for travel by four-wheel-drive vehicles and maintenance equipment.

Several years ago, an invitation to bid on agricultural use of the DOE tie-line rights-of-way for hay and other crops was unsuccessful.

2.3.3 Substations

By 1984, there will be five 161-kV DOE-owned substations, one 500/161-kV (Roane) substation owned by TVA, one 161-kV substation owned by TVA for city of Oak Ridge power, and four small 69-kV substations owned by the city of Oak Ridge. All substations will either be surrounded by cyclone fencing or enclosed in areas surrounded by cyclone fencing. The areas within the stations will be completely covered by crushed stone, except that the TVA Roane substation will be 30% covered by grass. The four city of Oak Ridge substations each are about three-fourths of an acre. The TVA substation covers about 45 acres. In 1984, the combined total area in the DOE substations will be about 33 acres.

2.3.4 Control measures

All transmission-line corridors along the ridges are either covered with grass or low-growing vegetation for erosion control. Some inaccessible areas are covered by kudzu and honeysuckle. Corridors across open fields are used primarily the same way as if the transmission lines were not there. The Comparative Animal Research Laboratory uses these corridors for their experimental crops and pasture. In the Y-12 area, corridors are used for equipment storage, parking areas, and other uses not requiring permanent installations.

Most DOE tie-line corridors are mowed once a year; the lines in the Y-12 area are mowed twice a year. Minimal quantities of herbicides are used on the DOE tie-line corridors. In unmowed areas in the Y-12 area, Esteron (1 qt diluted to 50 gal of water) is sprayed at a rate of about 100 gal per year. Control of weeds in switchyards and substations is accomplished by use of Pramitol 5PS pellets. About 1 ton of these pellets is used annually in the ORGDP and Y-12 switchyards.

Vegetation in the corridors of the TVA-owned and -maintained transmission lines is normally cut every three years by bush-hog equipment. In some areas where vegetation growth is slower, this period is extended to four years. If vegetation growth results in rodent infestation near residential areas, the time between cuttings is reduced. No herbicides are used by TVA in the Oak Ridge area.

2.4 REGULATORY STATUS

The ORGDP is an integral part of the uranium fuel cycle which is needed to help meet the current and projected electrical energy requirements of the United States. Being owned by the federal government, its operation is closely regulated and controlled to coincide with all other facets of the national energy program. For example, modification of existing diffusion equipment and the continued development of other uranium-enrichment methods are intended to provide additional enriched uranium for the growing number of nuclear power plants being constructed to help meet the nation's increasing demands for electrical energy.

Liquid effluents from ORGDP are regulated by NPDES permits issued by the EPA. The waste subsystems are currently in compliance with all best practical treatment requirements; the few instances of noncompliances with permit limitations are primarily pH and chlorine residual excursions.[5] Plans are being made to provide additional treatment systems to meet projected discharge requirements of the new Clean Water Act.

Airborne effluents from ORGDP are now under state regulation, as provided by the 1977 amendments to the Clean Air Act. Under these amendments, all airborne effluents (about 200 release points) must have state-issued discharge permits stipulating limits for the individual pollutants.

The regulation of solid waste disposal lies with the state of Tennessee under the provisions of the Resource Conservation and Recovery Act. Although the specific requirements of this regulation have not yet been stipulated, plans are being made to increase monitoring of existing burial areas and to provide for such efforts in new disposal areas.

The use of toxic materials at ORGDP is regulated by the Toxic Substance Control Act. Particular emphasis is currently placed on both the short- and long-term handling and disposal of PCB, which are used extensively in the plant's electrical transformers.

2.5 TANGIBLE BENEFITS

Generally, the economic benefit derived from ORGDP is twofold: national enhancement resulting from the economic value of the enriched uranium and local enhancement resulting from the plant payroll. The continuing operation of the plant will permit the United States to continue to fulfill its commitment to supply enriched uranium, thereby permitting existing nuclear power facilities to procure fuel for continued operation; the result is an avoidance of increased dependence on foreign oil supplies. Locally, the plant payroll lends support to community services and businesses.

Plant employees represent significant portions of the local communities and, therefore, contribute largely to the social life and status of those communities. The employees add heterogeneity to the communities; one result is heightened educational goals. Political enhancement derives from continued participation of plant employees in local governments and civic organizations. The presence of the professional segment of the community and the trained labor force tends to attract other businesses to the communities.

2.6 KNOWN ENVIRONMENTAL ISSUES

The ORGDP operations are, for the most part, free of controversial environmental issues. However, as with any operation of its magnitude, a few practices and operating philosophies are subject to some debate. The following sections address the more significant potential environmental issues and what actions, if any, are being taken to settle the controversy.

2.6.1 Waste heat disposal

More than 90% of the electrical energy used to transfer the UF_6 through the diffusion cascade is currently dissipated directly to the atmosphere as waste heat through evaporation of water from mechanical-draft cooling towers. By 1984, this heat release will be in excess of 1800 MW. Several alternatives are currently under study to determine the optimum method for recovering and using this energy. The options vary from conversion to electrical energy to use for space heating.

2.6.2 Scrap metal storage

As a result of the diffusion cascade improvement and uprating programs, an extremely large quantity of scrap metal, contaminated with radioactive material adhering to the surface, is being accumulated.

Since this metal is a valuable resource and has economic value, it is being stored at the K-722 powerhouse site (Fig. 2.1) in anticipation of reclamation. However, since legal restrictions currently prohibit the sale of any material containing enriched uranium or contaminated with mixed fission products, and since no existing system can produce completely "clean" metal, a market for this material does not currently exist. Therefore, no definitive plans have been made to reclaim it.

Because the metal is not totally decontaminated prior to storage, very small quantities of radioactive compounds are transported to the storage yard. Through rainfall and surface runoff, a small quantity of this radioactivity undoubtedly is transported to the Clinch River, which is immediately adjacent to the storage yard (Fig. 2.1). A sampling program was recently initiated to determine the actual quantities of uranium discharged from this area to the river as well as the concentrations contained in the ambient air, soil, and subsurface waters. Planning efforts relating to ultimate disposal or recycle are continuing; no date for completion has been determined.

2.6.3 Use of PCB

The ORGDP uses large quantities of PCB in several of the diffusion process electrical transformers and capacitors. Because this material has been determined to be hazardous, extreme precautions are taken to ensure that its use does not result in losses to the environment. For example, buildings containing the equipment in which PCB are used are being modified to provide complete secondary containment. Doors are being curbed, wall-to-floor joints are being sealed with a PCB-resistant caulking, and all floor drains are being permanently sealed. In addition, all liquid transfer operations, which are always implemented within the buildings, are surrounded by temporary sandbag dikes. Administrative controls include proper labeling of all PCB-containing equipment, explicit procedures for PCB handling and storage, and routine monitoring of the atmosphere around PCB-handling operations, as well as the liquid effluents from these operations. All waste PCB materials are collected and contained in specially marked, heavy-wall steel drums and shipped (in compliance with DOT shipping regulations) to a commercial disposal facility.

2.6.4 Technetium-99 and transuranic contamination

Several years ago ORGDP received UF_6 that had been prepared from reprocessed production reactor fuels. In addition to the uranium isotopes, small quantities of other radionuclides produced by the reactor were also introduced into the diffusion cascade. Included in these materials were technetium-99, plutonium-239, and neptunium-237. Whereas trace quantities of the transuranic materials (plutonium and neptunium) have been observed on some of the process equipment, none has been detected in any of the airborne or liquid effluents or in Poplar Creek. Significant quantities of technetium-99 have been detected in the process equipment and measurable quantities are routinely released in some of the airborne and liquid effluents. For example, in 1977, about 10 Ci of technetium-99 was released to area surface streams and about 1×10^{-6} Ci was released to the atmosphere. The airborne release of technetium-99 results from its presence in the purge cascade's effluent, whereas the major liquid source is the equipment decontamination operation. Neither presents a significant radiation dose to the public or to plant personnel.

A more detailed discussion of the technetium-99 releases and their subsequent contribution to the area population's radiation dose are presented in Sects. 2.2.3.3 and 5.1.2.

Studies are under way to determine the behavior of technetium-99 both inside the process system and in the environment. As a result of these continuing efforts, several very important facts have been learned:

1. The technetium-99 moves toward the product end (top) of the diffusion cascade.

2. Technetium-99 can be selectively removed from the UF_6 stream by use of magnesium fluoride traps. Removal efficiency varies considerably according to the technetium concentration.

3. Most technetium-99 compounds are extremely soluble in water.

4. Most soluble technetium-99 compounds can be removed from decontamination solutions by either reduction-precipitation or ion exchange techniques.

REFERENCES FOR SECTION 2

1. Energy Research and Development Administration, *Final Environmental Statement, Expansion of U.S. Uranium Enrichment Capacity*, ERDA-1543, April 1976.

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3. P. A. Jallouk, G. J. Kidd, Jr., and T. Shapiro, *Environmental Aspects of Cooling Tower Operation: Survey of the Emission, Transport, and Deposition of Drift from the K-31 and K-33 Cooling Towers at ORGDP*, K-1859, Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tenn., February 1974.

4. S. R. Harra, *Meteorological Effects of Mechanical Draft Cooling Towers of the Oak Ridge Gaseous Diffusion Plant*, ATDL No. 83, unclassified, U.S. Department of Commerce, NOAA, March 1974.

5. Union Carbide Nuclear Division, *Environmental Monitoring Report, United States Department of Energy Oak Ridge Facilities, Calendar Year 1977*, Y/UB-8, Oak Ridge, Tenn., June 21, 1978.

6. U.S. Department of Energy, *Manual 530*, Appendix II.

7. Health Physics Society, *ICRP Report of Committee II on Permissible Dose for Internal Radiation (1959)*, vol. 3, June 1960.

8. Energy Research and Development Administration, *Liquid Metal Fast Breeder Reactor Program Final Environmental Statement*, ERDA-1535, Dec. 31, 1975.

3. ALTERNATIVES

The alternative assessed in this report is the no-action alternative, which is the continued full-power operation of the Oak Ridge Gaseous Diffusion Plant in a 1984 time frame after the cascade improvement and cascade uprating programs have been completed. Alternatives other than continued full-power operation are discussed briefly in the following.

3.1 SHUTDOWN OR REDUCED OPERATION OF OAK RIDGE GASEOUS DIFFUSION PLANT (ORGDP)

The ORGDP provides enriched uranium to fuel nuclear power reactors. If the plant were to shut down, the United States could not fulfill its contractual agreements with private industry. Some additional capacity exists or is under construction outside the United States; however, it is doubtful that the existing and planned capacity of the foreign enrichment facilities will be sufficient to replace the capacity of ORGDP.

Routine operation at reduced power loads for the express purpose of minimizing environmental impacts would be only marginally effective. The production burden probably would be shifted to other domestic enrichment facilities or scheduled over a longer period. Either alternative would result in roughly equivalent long-range environmental impacts in terms of power consumption and pollutant loadings in operational effluents.

3.2 REPLACING THE GASEOUS DIFFUSION PROCESS WITH AN ALTERNATIVE ENRICHMENT TECHNOLOGY

An alternative to plant shutdown is to substitute another enrichment process for the gaseous diffusion process. The two most likely alternative processes are gas centrifuge separation and advanced isotope separation (AIS) techniques.

The impacts of diffusion vs centrifuge plants have been compared in depth in ref. 1. The replacement of a portion of the diffusion enrichment capacity with centrifuge technology is being studied; however, indications are that this alternative is not now economically justifiable and probably will not be until the mid- to late-1990s.

Environmental issues associated with an enrichment plant using AIS technology have been identified,[2] but the technology, although promising, is still in the experimental stages. Therefore, it is not considered in this assessment as an alternative to the continued operation of ORGDP.

3.3 RELOCATING ORGDP

The relocation of ORGDP as an alternative to shutting it down would necessitate development of a new site, which would entail environmental and socioeconomic impacts, as well as the impacts associated with power production. Environmentally, continued plant operation is vastly preferable to relocation, so this alternative will not be considered further.

3.4 POWER ALTERNATIVE

It is assumed here that ORGDP will continue to operate; it will have a power requirement of about 2080 MWe in 1984.

Under current contractual agreements, ORGDP receives power from the Tennessee Valley Authority (TVA) system and is considered the same as any other industrial customer.

Two alternatives for obtaining electrical power are considered below.

3.4.1 Power supplied by a government-owned dedicated plant

If power were supplied by a government-owned dedicated plant, a major consideration would be the impact such a plant would have on TVA's system. The existing TVA generation and transmission system was designed to accommodate, as efficiently as possible, the power demands of ORGDP and the other area consumers.

A dedicated plant would have to be large enough to have a reserve capacity of about 35% of the total ORGDP demand, or a total capacity of about 2800 MWe. For maximum operational efficiency, it would still be necessary to interconnect with the TVA system so that (1) TVA could supply power to the plant in an emergency and (2) excess power, when available, could be fed into the TVA system.

Therefore, location of a dedicated plant in the vicinity of ORGDP would adversely affect the balance and efficiency of the present TVA system and create a situation of less than optimum utilization of power production capability and transmission equiment by the duplication of facilities and capacity already provided for ORGDP demand.

3.4.2 Power supplied by a private utility

Currently, the capacity to supply the ORGDP power load does not exist in the private sector; therefore, the alternative of power supplied by a private utility outside the TVA area would first require construction of new production facilities. Specific environmental impacts of the construction of a new plant would depend on the site chosen; these impacts have not been quantified. Territorial agreements currently in effect would have to be modified, and extensive new transmission lines would have to be built, integrated, and coordinated with the TVA system. As with the dedicated plant alternative, this option would not provide for optimum utilization of power production capability and transmission equipment because of the duplication of facilities and capacity already provided by TVA to supply the ORGDP demand.

3.4.3 Conclusions on power alternatives

The previously described alternatives are considered much less desirable than is the current mode of operation. If either option were chosen over the current mode, the TVA system would continue to operate as it exists, and the environmental effects in the area of its plants would not be altered. The added environmental effects of new transmission lines and plant construction, as well as disruption of the TVA system to bring either option on line, would be much worse than the effects of the current mode of operation and would result in much higher energy costs than are currently incurred.

3.5 ALTERNATIVE SUBSYSTEMS

Alternative heat dissipation systems, chemical treatment of cooling systems, biocidal waste treatment, and polychlorinated biphenyl—containing systems were evaluated in ref. 3; the evaluations and conclusions reached are applicable to ORGDP operations. No further evaluation of these will be given in this assessment. Other subsystem alternatives are given in the following subsections.

3.5.1 Waste-heat utilization

The large amounts of waste heat rejected by the gaseous diffusion process through the recirculating cooling water system have been studied over the years as a possible source of recoverable energy.

One of the more promising schemes for recovering this energy consists of using it for heating purposes. A brief examination of this possibility immediately eliminates essentially all uses of this source of heat for any heating application other than building heating. The replacement of steam for heating of process pipe and interplant tie-line enclosures is not possible because the required temperatures are higher than the available 150°F heat source. The same is true of the steam required for feed vaporization and for such maintenance purposes as the heating of cleaning solutions.

Because the existing buildings already are equipped with heating systems, modifications would be required to faciliate the use of the recirculating cooling water. Such waste heat utilization is being considered because it would result in a savings in fuel and in a moderate reduction in the amount of effluents from the steam plant.

3.5.2 Radioactive waste alternatives

The only significant radioactive materials emitted from ORGDP are uranium (enriched in U-235) and technetium-99. Although these releases are well within the applicable radioactivity concentration guides (RCG) outlined in *DOE Manual Chapter 0524*, new and improved methods for rad effluent reductions are continually being researched and will be incorporated where applicable.

3.5.2.1 Gaseous rad effluents

In 1977, the average environmental concentrations of alpha and beta-gamma radioactivity in air at offsite locations ranged from 0.02% to 0.05% of the RCG. The total airborne uranium released from ORGDP was 6.6×10^{-4} Ci. This amount is expected to be about the same when the plant is up to a 2080-MWe power level in 1984. This amount is considered by the staff to be as low as practicable; there are no alternatives currently available to reduce emissions further. The problem presented by controls applied to the air emission sources is discussed in a following subsection on solid rad waste (Sect. 3.5.2.3).

3.5.2.2 Liquid rad effluents

The primary ORGDP generator of liquid radioactive waste is the equipment decontamination operation located in Building K-1420. Currently, this operation produces two liquid waste streams. One stream consists of water and steam condensate that has been used to remove radioactive materials from small pieces of equipment. This stream is discharged directly to the K-1407-B holding pond where, through pH control, a large portion of the uranium compounds are allowed to precipitate and settle. Soluble materials, such as technetium-99 compounds, are not precipitated and thus flow through the pond and into Poplar Creek via the K-1700 discharge location.

The second decontamination waste stream is currently piped to the uranium recovery operation in Building K-1420, in which, through a solvent extraction process, the uranium is recovered for recycle. The concentrated nitrate waste from this operation, which also contains small quantities of uranium and technetium-99 and trace quantities of transuranic compounds, is transported to the Y-12 Plant where the uranium and transuranic compounds are precipitated and settled in a holding pond, and the nitrates are biodegraded. The Y-12 nitrate waste and associated holding pond will be assessed in the Y-12 EA (in preparation).

In 1977, about half of the radioactivity (9 Ci) generated as waste by decontamination operations was transported to the Y-12 Plant and the other half was discarded directly to the ORGDP K-1407-B holding pond.

The alternatives to the current mode of operation would include provisions for reducing both uranium and technetium discharges. The most drastic reduction would be accomplished by collecting all decontamination solutions and trucking them to another facility equipped to remove the uranium and technetium.

Another alternative being evaluated involves the installation of equipment at the K-1420 facility to collect and recover the uranium currently being discarded to the K-1407-B holding pond. The resulting nitrate waste stream would then be combined with the existing nitrate waste and treated to remove the technetium-99 prior to shipment to the Y-12 biodenitrification facility. Total technetium discharges could be reduced by installating technetium-99 removal equipment, such as ion-exchange facilities, in both of the existing discharge streams.

All these alternatives are being evaluated on a cost-benefit basis with the recognition that, in the near future (1981), the quantities of waste radionuclides generated will be substantially reduced as a result of the completion of the cascade improvement and uprating programs.

3.5.2.3 Solid rad waste

The major sources of solid radioactive wastes at ORGDP are scrap metal from upgrading and maintenance operations and solid-trapping media from gaseous effluent controls. Recovery of the radioactive material from these solids is often based on the economic value of the materials. Further decontamination can, in some cases, be done, but the value of the recovered materials, and the usual low level of contamination remaining, seldom justifies such efforts. Most of the current solid rad waste handling systems consist of some form of ultimate burial.

It is the policy of the Oak Ridge Operations Office to conserve scrap metal values through direct sale or pretreatment and sale. In the case of metals contaminated with small quantities of enriched uranium it has been necessary to store these materials pending establishment of a *de minimus* quantity ruling by the Nuclear Regulatory Commission permitting unrestricted use of smelted metal. Smelting is very effective in removing uranium from ferrous scrap, resulting in a product whose residual radiation levels constitute a minimal hazard to potential users. An evaluation of possible radiation exposures has been sent to the NRC, who in turn has initiated preparation of an environmental impact statement in support of the *de minimus* quantity rulemaking. Due to procedural requirements and competition between this rulemaking and many other NRC activities it is not possible to state when the scrap will be available for smelting. Until then, the scrap will continue to be stored.

Solids generated from gaseous effluent controls currently are placed in retrievable storage in Monel cylinders, awaiting a decision on final disposition. Options being studied include (1) provisions for reclaiming both uranium and technetium as in the liquid rad waste options, (2) chemical fixation of radioactivity into a nonmobile state, followed by land burial, (3) disposal by hydrofracture; and (4) continuation of storage in a retrievable state.

A decision as to the appropriate method of disposal of technetium-contaminated MgF_2 traps has been deferred pending the completion of efforts to evaluate the alternative methods.

For ORGDP, the most likely alternatives are (1) cementing and shallow burial, (2) repository disposal, and (3) hydrofracturing (at the Oak Ridge National Laboratory). Other sites have removed technetium from waste streams by using ion exchange resins or precipitation, as well as MgF_2. Thus, the most appropriate disposal technique preferably would be capable of handling the various waste forms mentioned.

The use of cements for both the MgF_2 and the resins have thus far had mixed results because some mixes are much more leach resistant than others. Similarly, investigations of the environmental transport of technetium have shown highly variable rates of movement, depending on soil conditions.

Until these alternatives are adequately evaluated and there are sufficient data to support the decision, the traps will continue to be stored.

3.5.3 Nonradioactive pollution abatement alternatives

The operations of ORGDP are generally in compliance with all currently applied air, water, and solid waste management requirements. There are plans to make operational improvements relative to fluoride air emissions and certain NPDES criteria through two line-item projects currently in the federal budget for FY 1980. In addition, more extensive pollution-abatement efforts for various air, water, and solid waste regulations, most of which are only available in draft form at this time, are planned for FYs 1981 and 1982 and in the DOE-ORO long-range budget plans that extend to FY 1985. Before design and construction can proceed, these project plans must pass the DOE budget review process and analysis by the Office of Management and Budget, must receive congressional approval, and be authorized by the president.

3.5.3.1 Nonrad gaseous effluents

Three fluoride scrubbers will be added at ORGDP as part of the Gaseous Effluent Control Program, an FY-1980 line-item project. Two of the scrubbers will be used to remove elemental fluorine and hydrogen fluoride from a flow of air and/or nitrogen; the other scrubber will be used to remove hydrogen fluoride from a flow of hydrogen. One of the elemental fluorine scrubbers and the hydrogen fluoride scrubber will be located in the fluorine plant (Building K-1131); the third scrubber will be located at the gaseous diffusion pilot plant (K-1004-L). Aqueous potassium hydroxide solution will be used for the elemental fluorine scrubbers and solid potassium carbonate for the hydrogen fluoride scrubber. In K-1131, provisions will be made for regenerating the potassium hydroxide and carbonates consumed in neutralizing the fluorides by slurrying the potassium fluoride with lime and settling and/or filtering the resulting precipitate. The dewatered solids will be packaged and buried.

In K-1004-L the exhausted scrubbing solution will be transported to K-1407-A, treated to precipitate the fluorides, and released to the K-1407-B holding pond.

Proposed line items for future years may also provide controls for chlorofluorocarbon (Freon) releases from the cascade and controls for various airborne metals in work areas.

3.5.3.2 Nonrad liquid effluents

As part of an FY-1980 line-item project, Control of Water Pollution, several improvements are planned that will alleviate some infrequent compliance problems, or that will allow continued operation in compliance with current permit conditions.

Two settling ponds will be designed for the removal of 3.7×10^6 lb/year (dry weight) of alkaline solids from the ORGDP cascade recirculating makeup cooling-water softening process (K-892). Sludge from the K-892 softeners currently flows by gravity through storm drains to the K-901-A holding pond. This system is to be replaced by a sludge line that will allow the sludge to be pumped directly to the new settling ponds. The two ponds will be operated one at a time, in cycles. As one pond receives the sludge effluent from the softening process, the second previously filled one will be drained. The sludge dredged from the ponds will be buried. Each pond will be designed to contain a two-year accumulation. Provisions for flow measurement and grab sampling will be incorporated in the facility design to allow periodic effluent monitoring. Effluent from the ponds will be routed to an acid mix facility for neutralization. Sulfuric acid will be stored at this site, and a small prefabricated building will be erected for housing process instrumentation, and eye bath, and safety showers. The neutralized effluent will be discharged to the K-901-A holding pond. Minimal lighting and roads for access and for pond dredging will be provided at the site.

New reserve fire-protection-water pumping capacity will require the installation of two 4000-gpm pumps at the K-802 pumphouse located along Poplar Creek, at the north end of ORGDP. One of the pumps will be diesel-powered and the other electric. Reserve fire-protection water will be stored in the cooling tower basin (K-802-H), which will be cleaned out for this purpose. Sludge effluent removed during the cleanup will be routed through existing lines to the K-1203 sewage treatment plants.

Collection of evaporator condensates and raffinates containing nitric acid from the K-1420 uranium decontamination facility will require process piping modifications and installation of criticality-safe holding tanks. Neutralization of the collected effluents will require the construction of a neutralization facility north of Building K-1420. A prefabricated building will be erected to contain a batch-mixing tank with agitation, lime bag storage area, and pH control instrumentation. A tank-truck loading platform will be constructed adjacent to the neutralization area and a tank-truck will be purchased for transport of the neutralized waste to the Y-12 denitrification facility. The tank truck will also be used for storage of the waste at Y-12 until it can be fed to the denitrification facility. Solids resulting from the neutralization process will contain small quantities of nickel and uranium and will be collected and buried in appropriate containers.

The rerouting of acidic effluents from the softening operations at the K-1501 steam plant to the existing K-1407-A neutralization facility for pH control will require a pumping facility and about 1000 ft of overhead line, which will be partially supported by an existing pipe bridge.

Eight oil-removal pits will be constructed in storm sewers discharging to Poplar Creek from portions of the K-27, K-29, K-31, and K-33 process buildings. Earth excavations will be required to install reinforced-concrete sewer intercepters with double baffles for containment of any accidental oil spills.

Excessive groundwater infiltration in the ORGDP sewage collection system has caused hydraulic overloading of the sewage treatment plant. Rehabilitation of the sewage system in the main ORGDP area and the powerhouse area will require repair or replacement of sewer lines 6 in. and over in diameter. A sewage system rehabilitation program will be designed based on inflitration/inflow studies.

In other projects proposed for FYs 1981 and 1982, ORGDP will obtain various facilities needed to comply with the July 1, 1984, "best available treatment economically achievable" (BATEA) criteria of the Clean Water Act and other anticipated future requirements.

Surface runoff collected from the two ORGDP coal piles will be routed through new piping to a new settling pond located north of Building K-1420. The settling pond will be sized to contain the 10-year 24-hr storm runoff from the 6-acre coal-pile area. The effluent from the settling pond will be pumped to a pH adjustment and clarification treatment system located at the central neutralizing facility to allow precipitation of metals from the coal-pile effluent. Lime will be used for pH adjustment. The effluent pH will be between 6 and 9, and discharge will be through the K-1407-A neutralizing facility to the K-1407-B holding pond. The system will be instrumented to allow routine operation from the new central neutralizing building (K-1407-F), to be located between the K-1407-A neutralizing pit and the K-1407-B holding pond.

Shallow concrete dikes will be provided for 81 transformers in Building K-33, which contain polychlorinated biphenyls (PCBs). The dikes will be capable of containing 120% of the volume of PCB material housed in the transformer. The inside of the diked area will be coated with a PCB-resistant material. In addition, the 81 process-size transformers will be fitted with special PCB traps over their pressure relief systems to capture liquid material released as a mist in the event of operation of the relief devices. Sudden-pressure relays will be installed on the 39 units in Building K-33 that do not already have this protective system to shut down transformer operation in the event of a sudden pressure rise in the PCB coolant system.

Effluents from the K-1410 nickel plating facility currently flow to a 10,000-gal concrete holding tank for neutralization prior to discharge. A means for efficient precipitation of nickel from the effluent discharge will be provided. Two new pumps will be installed in the existing K-110 holding tank to pump the effluent through a new line to the K-1232 treatment facility, which contains chemical precipitation equipment. Minor modifications to the K-1232 facility will be required.

A new facility will be provided for equalization, pH adjustment, and chemical precipitation or other solids separation equipment for effluents from the K-1401 metals preparation facility, K-1413, K-1501 blowdown, rinse water from K-1420 metals treatment, and the K-1420 uranium decontamination second rinse water. The facility will be located between the K-1407-A neutralizing pit and the K-1407-B holding pond and will include the new central neutralizing building (K-1407-F). Equalization will be accomplished in a concrete holding tank with a corrosion-protection coating. The holding tank will provide equalization for effluents over a 24-hr cycle. The effluent treatment method will be chemical precipitation.

The central neutralizing facility will also include chemical precipitation equipment for treating coal-pile runoff.

An existing lime silo at K-1407-A will be used to supply lime requirements at the central neutralizing facility. The bottom of the bin will be modified to serve both existing needs and new facility requirements, including lime requirements for treatment of coal-pile runoff. The effluent from the chemical precipitation process will go to the existing K-1407-A neutralizing pit for final pH adjustment before discharge. Equipment requiring weather protection, such as the lime slurry system, will be housed in the new central neutralizing building (K-1407-F). The process will be controlled from this building. Coal sludges generated at the facility will be buried with fly ash generated at the steam plant. All other sludges generated at the facility will be disposed of at the sludge treatment facility.

Facilities for treatment of K-1420 floor pan and cylinder cleaning effluents also will be located in K-1407-F. Effluents will be stored in a holding tank for 24-hr; the tank will be designed to be criticality-safe (maximum 10 in. diameter). Effluent treatment will include pH adjustment, solids separation, and ion exchange. The treated effluent will be discharged to a backwash storage tank to be used in backwashing filters. Backwash will be discharged to the solids settling tank. Unit processes will be designed to maintain criticality safety. All sludges and resins will be discharged to the sludge treatment facility.

Sludges generated as a result of several of the new facilities will be treated in the sludge treatment facility. This facility will include a new building which shall be located south of the K-1407-C holding pond. Equipment for solids retention, dewatering, and fixation in concrete will be provided. Dry solid additives will be stored in bins and blended before mixing with sludges.

A new emergency return line from the K-792 switchyard will provide a spare return line in case of rupture or outage of the existing return line.

The existing sewage plant (K-1203) consists of an extended-aeration-activated sludge package treatment facility, chlorination equipment, and sludge drying beds. An effluent filtration system will be added after disinfection to provide additional removal of BOD and suspended solids from the sewage effluent. Filter backwash will be equalized and returned to the head end of the plant. The existing chlorine disinfection system will be replaced by an ozonation system, which will be located in a new building, K-1203-15. The building ventilation system will be designed to satisfy the quantity and quality of air required to meet safety environmental conditions applicable to ozone-generation equipment. A covered concrete contactor tank with an ozone-diffuser system will be provided. Vent gases from the contactor tank will pass through an ozone-destruction unit before being discharged to the atmosphere.

3.5.3.3 Nonrad solid waste

Several new treatment facilities will be proposed in the federal budgets for FYs 1981 and 1982 relative to the future requirements of the regulations pursuant to the Resource Conservation and Recovery Act (RCRA).

Miscellaneous sludges, including sludges from fluoride scrubbers, the K-1232 facility, the chromate reduction facility (Andco), and the K-1407-B and K-1407-C ponds will be transported to and treated in a central solid waste disposal facility. Solids from the K-1407-B and K-1407-C ponds contain small amounts of uranium and/or transuranics. These solids will be fixed in concrete and contained in coated concrete vaults for aboveground storage at the old contaminated burial ground north of Building K-33. Several inches of dirt from the bottom of the K-1407-C pond will also be fixed and contained in vaults. Other potentially hazardous solids will be fixed in concrete and transported to an approved burial site.

The facility will consist of pond dredging and solids-handling equipment (for removing sludges from the K-1407-B and K-1407-C ponds over an approximate two-year period), tank-truck transport, retention tanks, dewatering equipment, high-energy mix equipment, dry chemical bins with mass-flow meters, a dry-chemical blending system, coated concrete vaults, a vault storage area, and ancillary pumps and piping. Dedicated equipment such as forklifts or cranes for moving vaults, concrete trucks, and pickup trucks will be provided to allow proper operation of the solid-waste-handling facilities.

A water treatment system incorporating pH adjustment and chemical precipitation equipment will be provided for the removal of fluoride from fluoride-scrubber effluents and for treatment of liquid effluents from sludge treatment.

Sludges will be collected from the Andco chromate-reduction unit by a new laminar settling clarifier sized to treat 600 to 800 gpm. The effluent discharge line from the Andco unit will be intercepted by a sump and pumped to the laminar settling clarifier. A polymer feed system will be designed for the clarifier. The supernatant will be discharged to the K-901-A holding pond.

Sludges collected from the clarifier will be pumped through a continuous centrifuge (housed in a new small process building), collected, and transported to the central solid waste disposal facility for fixation. The supernatant will be discharged to the K-901-A holding pond.

REFERENCES FOR SECTION 3

1. *Final Environmental Statement. Expansion of U.S. Government Capacity*, ERDA-1543, U.S. Government Printing Office, Washington, D.C., April 1976.

2. U.S. Department of Energy, *Environmental Development Plan. Advanced Isotope Separation*, DOE/EDP-0022, March 1978.

3. *Final Environmental Statement. Portsmouth Gaseous Diffusion Plant Site*, 2 vols., ERDA-1555, U.S. Government Printing Office, Washington, D.C., May 1977.

4. CHARACTERIZATION OF THE AFFECTED ENVIRONMENT

4.1 REGIONAL DEMOGRAPHY

The 640-acre Oak Ridge Gaseous Diffusion Plant (ORGDP) site is part of the approximately 37,300 acres of federally owned land in Anderson and Roane counties, Tennessee. This land, generally called the Oak Ridge Reservation, is the responsibility of the U.S. Department of Energy (DOE). The reservation is surrounded by five counties – Anderson, Knox, Loudon, Morgan, and Roane – which have a combined 1975 population estimate of 437,600 (a 6% increase over the 1970 population of 413,359).

There are two major population centers within 50 miles of the site: the city of Oak Ridge (1970 population: 28,319), the populated area that directly borders the northern edge of the reservation, and the city of Knoxville (1970 population: 174,587), about 25 miles east of the site. Other cities within the five surrounding counties are Clinton (population, 4794), Harriman (8734), Kingston (4142), Lenoir City (5324), Loudon (3728), Rockwood (5259), and Oliver Springs (3405).

Figure 4.1 shows communities with populations over 1500 that are within 100 km (60 miles) of the reservation. Table 4.1 lists radial sector population distribution around the ORGDP site.

Table 4.1. Incremental population around the ORGDP site[a]

Direction	Radial distance (miles)						Total
	0–5[b]	5–10	10–20	20–30	30–40	40–50	
N	0	0	776	1,040	6,836	4,471	13,123
NNE	382	4,518	1,401	8,183	9,231	7,518	31,233
NE	0	11,925	19,762	9,807	6,229	3,562	51,285
ENE	0	5,280	10,595	50,371	18,761	9,570	94,577
E	1,490	0	20,736	151,855	28,389	13,784	216,254
ESE	0	0	8,108	42,146	8,421	5,704	64,379
SE	0	1,374	8,472	9,583	844	46	20,319
SSE	0	943	9,312	3,917	742	469	15,383
S	733	721	2,572	11,712	9,464	7,038	32,240
SSW	0	380	2,219	3,688	18,073	6,394	30,754
SW	622	3,639	1,537	2,493	4,796	11,240	24,327
WSW	0	1,707	10,456	2,176	3,688	4,186	22,213
W	666	10,041	1,012	1,588	11,394	3,748	28,449
WNW	0	1,548	2,355	0	886	3,145	7,934
NW	0	0	1,291	3,898	3,179	6,326	14,694
NNW	587	4,080	506	1,718	3,323	675	10,889
Total	4,480	46,156	101,110	304,175	134,256	87,876	678,053

[a] Longitude, 84°23′52″; latitude, 35°56′6″.

[b] Because of the large enumeration areas and the small sector sizes, the 0–5-mile counts cannot be considered precisely accurate.

Source: P. R. Coleman and A. A. Brooks, *PANS: A Program to Tally Population by Annuli and Sectors*, ORNL/TM-3923, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1972.

Fig. 4.1. Communities with a population greater than 1500 within a 100-km radius (60 miles) of the Oak Ridge Reservation.

4.2 LAND USE

The region near the site of the ORGDP encompasses areas of residential, agricultural, industrial, and recreational uses. The Oak Ridge Reservation covers about 15,100 ha (37,300 acres), including the land immediately surrounding ORGDP. The following information is necessarily brief. More detailed information is available in the environmental report and the final environmental statement on the Clinch River Breeder Reactor Plant (CRBRP).[1,2]

4.2.1 Residential land use

The site area has a low population density primarily because of the federal reservation land. The nearest privately owned land is about 3 km (2 miles) west of the site. Population centers near the site include Oak Ridge [10 km (6 miles) NE], Oliver Springs [13 km (8 miles) NNE], Kingston [14 km (9 miles) WSW], Lenoir City [19 km (12 miles) SSE], Loudon [23 km (14 miles) S], and Harriman [15 km (9 miles) W]. Residential land uses within the East Fork Poplar Creek Valley (NE-SW) are limited to distances greater than 5 km to the southwest and 7 km to the northeast. Oak Ridge residential areas occur no closer than about 10 km (6 miles) northeast of the site.

4.2.2 Agricultural land use

Farming in east Tennessee has followed the national trend of a steadily decreasing number of farms and of the remaining farms increasing in average size. The trend has been to shift from dairying and other forms of labor-intensive farming to raising beef cattle, which requires less labor. Beef cattle production doubled from 1939 to 1964[3] and nearly doubled again in the five-year period of 1964 to 1969. In 1974, about 475 head of beef cattle were counted within 5 miles of the site.[4] Scattered herds of 20 to 30 head were located in the southeast, southwest, and northwest quadrants. Interspersed with the beef cattle were 61 milk cows. There are no commercial dairy farms within the 10-mile radius in Morgan, Anderson, or Knox counties;[3] there are four in Roane County and one in Loudon County.

The principal cash crops harvested in the five counties are tobacco, corn, soybeans, and wheat. Table 4.2 shows the number of acres and yields of these crops. Table 4.3 shows the total number of farms and the percentage of land devoted to farming in each county in 1969.

Table 4.2. Principal cash crops in the five counties surrounding ORGDP, 1969

	Tobacco		Corn		Soybeans		Wheat	
	Acres	Pounds	Acres	Bushels	Acres	Bushels	Acres	Bushels
Anderson	221	430,000	391	30,000	0	0	6	60
Roane	267	472,721	1,192	63,465	342	7,200	40	1,190
Morgan	85	174,379	1,612	125,211	117	1,690	125	4,340
Knox	575	1,076,077	1,425	73,901	0	0	79	2,963
Loudon	637	1,098,053	1,353	76,949	733	18,474	525	22,113

Source: *Tennessee Statistical Abstracts 1974.*

Table 4.3. Selected land-use statistics of the five counties surrounding ORGDP, 1969

	Total land area (ha)	Percentage of total land in commercial forest	Percentage of total land in farms
Anderson	88,306	64.3	26.7
Roane	100,487	52.8	38.0
Morgan	139,622	84.5	19.0
Knox	136,384	31.5	39.2
Loudon	64,509	33.2	73.1

Source: *Tennessee Statistical Abstracts 1974.*

Commercial forest land (land that is producing or is capable of producing crops of industrial wood and is not withdrawn from timber use) accounts for more than half the land area in the surrounding five counties (Table 4.3). Many of the logged areas are replanted in fast-growing pines. Most of the federally owned land in the vicinity of the site is under a forest management plan that requires periodic logging.

4.2.3 Industrial land use

Among industrial users in a 16-km (10-mile) radius are the three DOE plants, which employ about 15,000 people. One of these plants, ORGDP, is the subject of this *document* (Sect. 2 describes its operations); all three plants are described in the CRBRP statements.[1,2] Three small industrial activities are located west of the ORGDP site in the Clinch River Consolidated Industrial Park. The U.S. Nuclear, Inc., plant occupies 10 acres for the fabrication of neutron absorbers and fuel elements for test reactors; future plans include the production of fuel elements for power reactors. U.S. Nuclear, Inc., employs about 25 people and will expand to a maximum of about 50 people in the indeterminate future. Nuclear Environmental Engineering, Inc., a small plant on a 5-acre tract, calibrates radioisotopes for use in education, research, and industry. The plant also is capable of manufacturing radioisotope generators and radioactive tracers for oil fields or other uses. This plant started with about 20 people and eventually will increase to a planned total of 75 people. Nuclear Assurance Corporation contains facilities to clean uranium hexafluoride (UF_6) containers. The recovered UF_6 will be returned to their customers. Nuclear Assurance Corporation employs about 6 people and will expand to a maximum of 45 people in about five years. All nuclear material handling by these three industries is done under controlled conditions in accordance with governing safety and health regulations. The site for the proposed CRBRP is adjacent to the industrial park.

4.2.4 Energy extraction and use

Nearby Tennessee Valley Authority (TVA) facilities include the Kingston Steam Plant [11.3 km (7 miles) SW] and the Bull Run Steam Plant [21 km (13 miles) NE]. Two reservoirs (Melton Hill and Watts Bar) adjoin DOE land near ORGDP. Each contains hydroelectric-power-generating equipment and navigation locks.

There is no mineral or energy extraction within the 16-km (10-mile) radius; coal mining is important in the region, however, particularly in Morgan County.

4.2.5 Recreational land use

Recreational areas within the 16-km (10-mile) radius of the site are shown in Fig. 2.2-7 of ref. 1; the companion table shows the estimated number of persons at each site during peak-hour use and the type of activity. Peak-hour use was assumed to be on July 4. Projections for peak hours for the years 1980, 1990, 2000, and 2010 are included. Based on 1970 information, the peak-hour recreational use of these facilities could result in 3565 persons being present at one time within the 10-mile radius of the site. This number could increase to 12,885 by the year 2010. If it is assumed that all these visitors reside outside the 10-mile radius of the site, this would represent an increase of about 8% over the permanent population of the site.

A 30-unit commercial camping and day-use area is located about 10 km (6 miles) southeast of the site. The maximum number of people (at any one time) at this campsite is estimated to be 80 in 1980 and 100 in 1990. A 100-unit commercial camping site under development on the Caney Creek embayment near Clinch River Mile (CRM) 17 is about 7 km (4 miles) from the southeast boundary of the site. Estimates of the maximum number of people at this campsite for 1980 and 1990 are 270 and 340 people respectively. Activities at the campsite will include fishing, boating, and swimming. A small stock-car racetrack located about 5 km (3 miles) southeast of the plant site currently may attract 5500 and 6000 fans, but this number could increase to 6500 in 1990.

In addition to the land areas set aside for recreation, much of the private and government land is enjoyed by both residents and tourists for its beauty. Many families occasionally drive along the scenic roadways; therefore, roadside areas have value beyond their current use.

4.2.6 Public facilities

There are no military installations within the 10-mile radius of the site. Schools within the 10-mile radius are listed in Table 4.4. Industrial and recreational facilities are discussed in Sects. 4.2.3 and 4.2.5 respectively.

Table 4.4. Schools within a 10-mile radius of ORGDP

System	Name	Grades	Enrollment 1971	Enrollment 1980	Enrollment 1990
Loudon County	Browder	1–8	111	200	250
	Eatons	K–8	638	800	850
	Highland Park	K–8	380	600	700
Lenoir City	Lenoir City High School	9–12	910	950	1000
	Lenoir City Junior High School	5–8	472	700	800
	Nichols School	K–4	401	750	800
	West Hill	1–6	113	250	300
Morgan County	Coalfield Elementary	1–8	375	375	375
	Coalfield High School	9–12	183	200	200
Roane County	Edgewood[a]	1–6	110		
	Cherokee	1–6	294	500	600
	Dyllis	1–8	211	300	300
	Emory	1–8	118	200	300
	Fairview	K–6	200	200	250
	Kingston Elementary	K–6	675	750	900
	Kingston Junior High School	7–8	351	500	600
	Roane County High School	9–12	814	1000	1200
Harriman	Cumberland Junior High School	7–9	345	600	650
	Harriman Central Elementary	1–6	362	600	700
	Harriman High School	10–12	504	850	900
	Margrave	5–6	109	125	125
	Walnut Hill	1–4	225	500	500
Oak Ridge	New elementary	K–6			725
Anderson County	No schools are within 10 miles of the site, and none is forecast for 1980 or 1990				
Oak Ridge	No schools are within 10 miles of the site. A new elementary school (kindergarten through 6th grade) is likely by 1990 in western Oak Ridge to accommodate 725 students				
Knox County	No schools are within 10 miles of the site, and none is forecast for 1980 or 1990				

[a]No longer functional as a school.

Source: Project Management Corporation and the Tennessee Valley Authority, *Clinch River Breeder Reactor Project, Environmental Report,* Docket No. 50-537, Apr. 2, 1975, Table 2.2-16.

There are no hunting areas in the immediate vicinity of the site (hunting is not permitted on the reservation); nor are there any wildlife preserves or sanctuaries. A waterfowl refuge which is part of the Long Island Wildlife Management Area is located on the Tennessee River about 16 km (10 miles) west-southwest of the site. The ponds on the west side of the ORGDP site, including the adjacent lowlands, are reserved as a natural wildlife refuge. This area serves as a habitat for coots and other waterfowl. About 69 ha (170 acres) of the area is also used as a natural study location for ecological observation and experimentation. The Tennessee Game and Fish Commission planted several pairs of adult Canadian geese on TVA land in the Melton Valley to establish a breeding colony. The program is a success: Many broods have been raised successfully.

One major highway, U.S. Interstate 40 (I-40), passes about 10 km (6 miles) south of the plant site. The closest interchanges on I-40 are state highway routes 58 and 95. The average traffic count on I-40 between the exits for Rts. 58 and 95 for a 24-hr period is 16,500 vehicles.[5]

Harriman Junction, about 13 km (8 miles) northwest of the site, has the closest rail mainline. It is served by the Southern Railway [Cincinnati, New Orleans and Texas Pacific (CNO&TP)].

The four airports located near the site are:

Name	Type	Distance and direction
Meadowlake Air Park	Sport	19 km (12 miles) SW
Oak Ridge Air Park	Sport	13 km (8 miles) NNE
Rockwood Municipal	Business and sport	29 km (18 miles) W
McGhee-Tyson	Commercial	37 km (23 miles) ESE

McGhee-Tyson (Knoxville) is the only airport with scheduled commercial flights. The nearest flight path, V16, is about 16 km (10 miles) south of the site. Aircraft approaching McGhee-Tyson would be at a minimum altitude of 1500 m (5000 ft) as they pass 16 km (10 miles) south of the site. The nearest holding pattern for McGhee-Tyson is about 50 km (30 miles) northeast of the site.

The construction of an airport in Oak Ridge for business and sport is under consideration by the city of Oak Ridge.

4.3 GEOLOGY

4.3.1 Topography and drainage

The ORGDP site is situated in the Valley and Ridge Subregion of the Appalachian Highlands Province. This subregion consists of a series of northeast-southwest trending ridges bounded by the Cumberland escarpment on the west and by the Blue Ridge Front on the east. The long, narrow symmetrical ridges are breached at irregular intervals by stream channels, which otherwise follow the trend of the ridges. The ORGDP is located between two of these ridges, Blackoak Ridge to the northwest and Pine Ridge to the southeast (Fig. 4.2). East Fork Ridge is between Blackoak and Pine ridges but terminates northeast of the site.

A small remnant of East Fork Ridge — McKinney Ridge — borders the site on the northeast. Poplar Creek cuts through the site from the northeast and joins the Clinch River to the southwest. Maximum relief in the immediate vicinity is 420 ft, from the surface of the Clinch River to the top of McKinney Ridge. This is typical for the Oak Ridge area. The ridges have a fairly uniform elevation of 1000 to 1100 ft; the valleys are about 800 ft in elevation. The elevation of the ORGDP site varies from 750 to 800 ft; the plant structures are between the 760 to 780 ft contours.

Near the site, Poplar Creek has a surface elevation slightly above 741 ft. Just north of the site, the East Fork joins Poplar Creek, flowing out of East Fork Valley from the northeast. A number of smaller ephemeral streams drain into Poplar Creek from the ridge flanks, forming the trellis pattern typical of this area. Within or adjacent to the site are a number of ponds and backwaters which are either drowned tributaries or sections of old stream channel cut off from Poplar Creek.

The plant site occupies virtually all of the area resulting from the small delta formed by the confluence of Poplar Creek and the Clinch River. Judging by the very limited influence on valley topography and local drainage, the delta sediments can be expected to be relatively shallow, not more than a few tens of feet thick. The original topography of the delta has been almost completely altered by site work for the ORGDP. The structures and yards occupy virtually all of the delta, extending to the ridges on all sides except the southwest, which opens toward the Clinch River. Physical isolation is created by two parallel ridges which extend beyond the site to the Clinch River. McKinney Ridge partially blocks the valleys to the northeast, and the Clinch river cuts across them to the south. The result is roughly a three-sided enclosure, bordered by the Clinch River on its open side.

4.3.2 Stratigraphy

The major stratigraphic units underlying the site and its confining ridges are the Rome Formation, the Conasauga Group, the Knox Group, and the Chickamauga Limestone. They range in age from Lower Cambrian (Rome Formation) to Middle Ordovician (Chickamauga Limestone). Within these formations, mapped in this area by McMaster[6] (Fig. 4.2), there are a number of uniformly recognizable rock units. These formations have not been separately mapped except for the Rome Formation, which has a siltstone and a shale differentiated. Normally, the members more resistant to weathering identify the formation because the softer shales and soluble limestones have been eroded and covered with soil and vegetation. Contacts between members are often gradational and discontinuous, which makes precise identification of intraformation contacts difficult.

In contrast, the major formations are mostly defined by erosional or structural boundaries and are more easily recognized. Many of the formation contacts in this area are defined by strike faults, where older rocks have been thrust over younger rocks toward the northwest. However, the topography of the area is influenced primarily by differential erosion rather than structural deformation.

In the immediate area of the ORGDP site (Fig. 4.2), four formations are recognizable.

1. The Rome Formation, of Lower Cambrian age, consists of two distinct rock units. The lower unit is silty shale and is bound on both contacts by faults — the Whiteoak Mountain Fault, which runs through the southeast corner of the site, roughly paralleling the Oak Ridge Turnpike, and a parallel fault separating the shale contact from the upper unit. The shale thickness is estimated to be 800 to 1000 ft in the Oak Ridge area.[6] The exact stratigraphic position has not been confirmed for this unit since it has been faulted on both surfaces and has no identifiable fossils or other features correlative with local units. A general description of the Rome Formation, including the shale member [identified as Ꞓrs on the geologic map (Fig. 4.2)] and the siltstone-sandstone member (identified as Ꞓr), is given in Appendix A.

2. The Conasauga Group, of Middle to Late Cambrian age, consists of a calcareous shale interbedded with thinner layers of limestone and siltstone (identified as Ꞓc in Fig. 4.2). Most of the ORGDP site is underlain by the Chickamauga Limestone, with the exception of a triangular section of Conasauga shale in the southeast part of the site and the area around McKinney Ridge (Fig. 4.2). This triangular section is in contact with an irregular section of Knox Dolomite. These two sections rest unconformably on the younger Chickamauga Limestone, bound on two sides by faults. The same sequence of Conasauga and Knox is found northwest and southeast of the site where the Conasauga shale, being less erosion resistant, underlies Bear Creek and Poplar Creek valleys. The Knox, which is much more resistant, supports Chestnut and Blackoak ridges. The section of Conasauga found within the site is between the Whiteoak Mountain Fault and a branch that begins just south of the site. A general description of the Conasauga Group in the Oak Ridge area is given in Appendix A.

3. The Knox Group (Late Cambrian to Early Ordovician; identified as OꞒk in Fig. 4.2) occupies only minor portions of the ORGDP site. These are (1) at the base of Blackoak Ridge on the northwest corner of the site and (2) an area southwest of McKinney Ridge which grades into the Conasauga south of Blair Road. As previously described, this section of the Knox-Conasauga sequence is thrust over the Chickamauga Limestone underlying East Fork Valley and is bounded by Whiteoak Mountain Fault and one of its branches. Along the base of Blackoak Ridge at the northwestern edge of the site, the upper surface of the Knox is in contact with the Chickamauga Limestone and is generally defined by the change in slope. The precise contact is not distinct in this area and is only inferred. This contact is more definitely identified in East Fork Valley to the northeast (Fig. 4.2). A general description of the Knox Group is given in Appendix A.

4. The Chickamauga Limestone (Middle to Upper Ordovician; identified as Och in Fig. 4.2) is exposed in the site area in East Fork Valley and in a small, complex section north of McKinney Ridge. Bethel Valley, to the southeast, is also underlain by it. Except for the overthrust sections mentioned previously, most of the ORGDP site is underlain by the Chickamauga. This formation has a complex lithology and contains bentonite layers near the base and toward the top of the formation. Bentonite is a notoriously poor

Fig. 4.2. Geologic map of the ORGDP site. Key: Chickamauga Limestone ( ) — limestone, shaly and silty; cherty; dense to crystalline; gray to gray-blue; fossiliferous; thin to medium beds; disconformity within formation and, at base, about 2200 ft thick. Knox Group ( ) — dolomite, cherty; dense to crystalline; light to medium gray; thin to massive beds, 3000 ft thick. Conasauga Group ( ) — shale, siltstone, with thin limestone layers in lower two-thirds, massive limestone in upper third, 1500 ft thick. Rome Formation ( ) — Ꞓr = siltstone, shale, sandstone, variegated; thin to medium, even beds; primary structures common, over 800 ft thick; Ꞓrs = shale, pure to silty, minor amounts of sandstone; chalcedonic chert cobbles strewn on surface, thickness unknown. Formation contact ( ) — contacts are all inferred; locations are approximate. Fault ( ) — fault lines are all inferred; locations are approximate. Source: W. M. McMaster, *Geologic Map of the Oak Ridge Reservation, Tennessee*, ORNL/TM-713, Oak Ridge National Laboratory, Oak Ridge, Tenn., Nov. 22, 1973.


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foundation material because it can expand when moist and cause differential heaving of structures built on it. The bentonite layers described by McMaster[6] may be present in the site area, but they are not identified in Fig. 4.2. A general description of the Chickamauga is given in Appendix A.

4.3.3 Structure

The most important structural features near the ORGDP site are the fault system consisting of Whiteoak Mountain Fault, which runs through the southeastern corner of the site, and a parallel fault that roughly defines the northwestern margin of Pine Ridge (Fig. 4.2). A branch of the Whiteoak Mountain Fault originates just south of the site, running due north through its center to McKinney Ridge. Here it turns along the base of the ridge into East Fork Valley and terminates after about 1 mile. Between the branch and the main fault lies a displaced section of the Knox-Conasauga sequence, which has been thrust over the younger Chickamauga Limestone underlying East Fork Valley.

The amount of stratigraphic displacement along Whiteoak Mountain Fault has not been determined. This multibranch fault originates about 20 miles northeast of the site, near Clinton, Tennessee, and extends southwestward across the state. Along the length of the fault, older rocks of the Rome Formation have been thrust northwest over younger rocks, here represented by the Chickamauga Limestone.[7] A parallel fault to the southeast separates two members of the Rome Formation, the lower shale and the upper siltstone. A section of undetermined thickness has apparently been faulted out of the Rome along the base of Pine Ridge.

Neither fault appears to have any topographic expression, and it is assumed that displacement took place prior to development of the present erosion surface. The fault planes dip steeply to the southeast at an angle of about 45°, parallel to or slightly steeper than the bedding planes. No seismic events have been associated with these faults near the site,[8] and no surface movement along the faults has been reported. These faults can probably be considered inactive, but no confirmation is available. A detailed investigation would be required to estimate when the latest movement along these faults took place.

4.3.4 Soils

No reports of a detailed site-specific investigation of soil characteristics at ORGDP are available.

A generalized description of soils in the Oak Ridge area is given by Carroll,[9] and a detailed description of soils in the nearby Whiteoak Creek Basin is given by McMaster and Waller.[10] The typical soil types of the Valley and Ridge Province, as in much of the Southeast, are red-yellow podsolic, reddish-brown lateritic, or lithosols. They usually are strongly leached, acid, low in organic content, and have exchange capacities of less than 10 milliequivalents per hundred grams of soil.

The depth of alluvium beneath the site area ranges from near zero to 60 ft.[8] Soils developed on the Chickamauga Formation, which underlies most of the site, are typically yellow to yellow-brown montmorillonites which contain small chips of chert, pebbles of siltstone, and small blocks of limestone.[10] The Conasauga Shale underlying the southeast section of the site develops a silty brown, tan, greenish, and maroon clay which is micaceous and contains fragments of unweathered parent rock. At least five distinct rock units have been identified within the Conasauga in Bethel Valley, and all have variable soil descriptions.

Although the primary determinant of the rate of migration of pollutants in the ground is the movement of groundwater, soils play an important role in retaining toxic contaminants such as radionuclides. Clays and their parent rocks, the shales, are excellent filter media. They generally have low hydraulic conductivities and are chemically active because they contain a large variety of charged ions which can exchange with and immobilize certain toxic metals. It should be recognized, however, that few rock or soil units are homogeneous. Although the average transmissivity of a rock or soil unit may be very low, a discontinuity such as a buried stream channel filled with sand or a fault zone can transform an impermeable barrier into a pipeline.

A detailed investigation is required to evaluate the retention characteristics of the soils of a specific site. At the ORGDP site, there are a number of geologic features that could provide rapid transmission of water through and away from the site. The most obvious is the fault that runs through the center of the site, across one limb of Poplar Creek, and the Clinch River. Another possibility is buried stream channels (remnants of Poplar Creek) beneath the site. They are typically filled with coarse sand and gravel and make excellent aquifers. The lithologic description of the Chickamauga (Appendix A) indicates eight distinct rock types. Contacts between rock units are often more hydraulically conductive than the rock units themselves. Although the Chickamauga is not considered to have a high hydraulic conductivity, local solution channels may exist. This is discussed more fully in Sect. 4.4.

4.3.5 Seismic risk

The major elements involved in evaluating seismic risk for a particular area are the geology (strata, soil) and seismicity of the area in question. Theoretical knowledge of crustal strain buildup and the length and type of fault systems allows estimates to be made of the maximum probable earthquake based on recurrence estimates and potential energy release. Seismicity, the relative frequency and distribution of earthquakes near a site, forms the basis for estimating the probability of a seismic event at a particular site. The relative frequency and distribution of earthquakes are obtained from the seismic history of the site. Seismic history is based on recorded and inferred historical data on the damage envelopes around the focus of large seismic events. Since many high-risk zones are based on one or two events, these data indicate only the potential, not probability, for damage. There is a correlation between the recurrence interval and magnitude: The largest events have the longest interval and therefore have fewer events recorded on which to estimate their recurrence time.

Energy is attenuated with distance from the focus of the earthquake. A complex estimate can be made of the ability of soils near the site to damp seismic energy transmitted toward a structure. By studying the site, foundation properties, and the structure design, an estimate can be made of the maximum earthquake that the structure could withstand without collapsing. These estimates are considered hypothetical since none has been tested by actual events.

Dames and Moore,[8] in their seismic risk evaluation of ORGDP, conclude that the maximum-magnitude allowable earthquake is 6.5 (MM scale) within 20 to 70 km of the site. McClain and Meyers,[11] in their evaluation of the seismicity of the southeastern United States, indicate that the probability of an event of that magnitude is quite small. They estimate that the largest earthquake to be expected within a 40-year interval for the southern Appalachians is of magnitude 6.6; for a 100-year interval, it is 7.3. These are considered rather crude estimates of the recurrence interval.[12] Examples of damage to be expected from intensity 7.3 earthquakes are (1) weak chimneys broken off at the roof line, (2) damage to weak masonry of low standards of workmanship, (3) some cracks in masonry of ordinary workmanship, (4) fall of plaster, loose bricks, and stones, and (5) damage to concrete irrigation ditches.[13]

4.4 HYDROLOGY

4.4.1 Surface water

4.4.1.1 Description

The ORGDP site is located near the confluence of the Clinch River (a tributary of the Tennessee River) and Poplar Creek on the Oak Ridge Reservation (Fig. 2.1). The operation of ORGDP, therefore, potentially affects the aquatic environments of both streams. There are effluent discharge points on both Poplar Creek and the Clinch River and two water withdrawal points on the Clinch (Sects. 2.2.3.3 and 5.3.1).

All waters that drain from the Oak Ridge Reservation eventually reach the Tennessee-Ohio-Mississippi water system. The headwater tributaries for the Tennessee River arise from points in Virginia, North Carolina, and Georgia. The total Tennessee River drainage area of 106,000 km^2 (40,910 sq miles) includes about 80% of the state of Tennessee, a major segment of northern Alabama, and regions of Kentucky, Mississippi, Georgia, Virginia, and North Carolina (Fig. 4.3). Many multipurpose dams regulate flow in this river system — the Tennessee River alone is dotted with nine mainstream reservoirs from Knoxville to Paducah, Kentucky.[14]

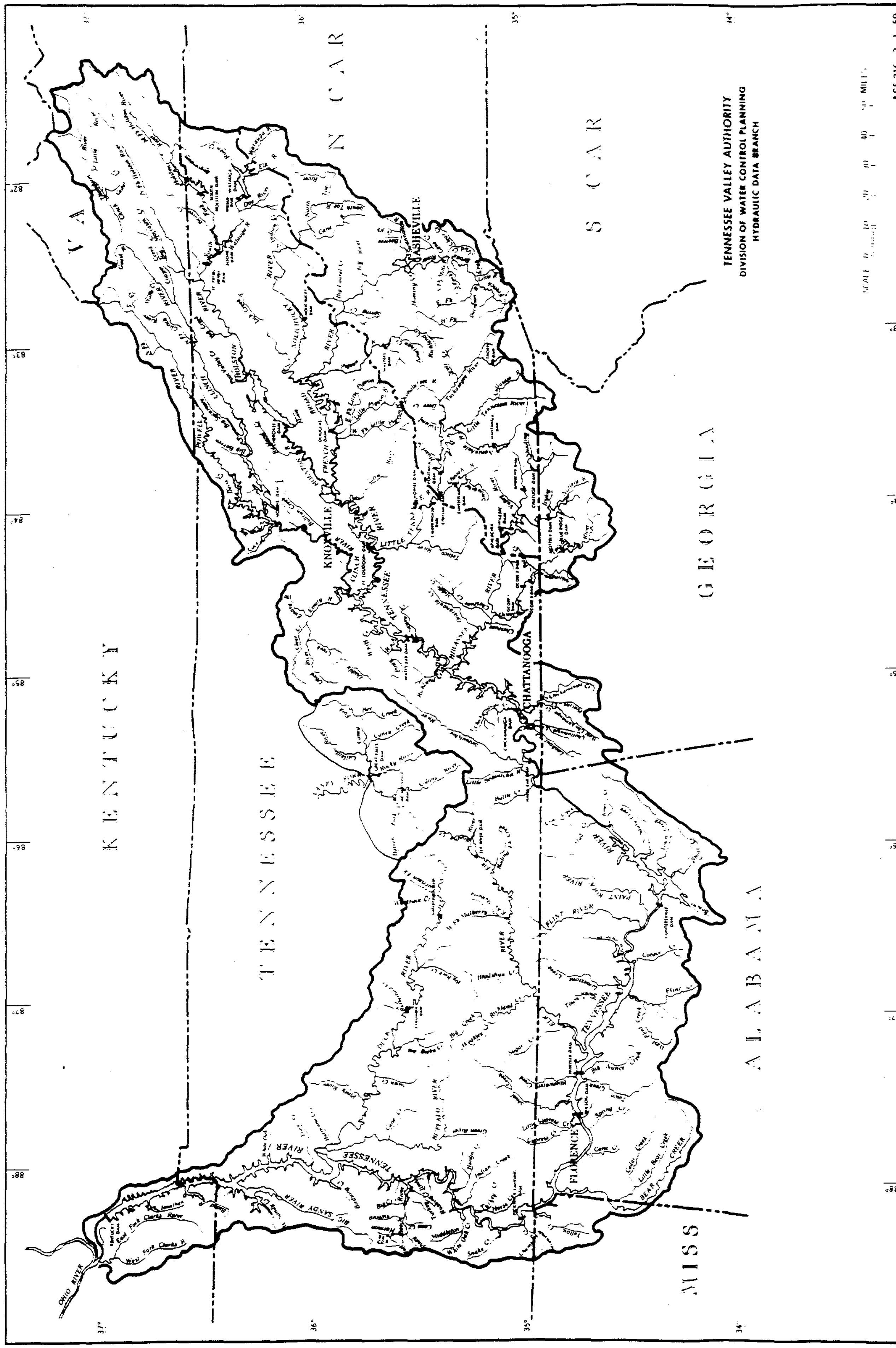

Fig. 4.3. Tennessee River Basin.

Clinch River

The Clinch River provides the immediate receptacle for waters discharged from the Oak Ridge Reservation. The Clinch originates in the southwest corner of Virginia near the Kentucky border, 280 air km (175 air miles) northeast of Oak Ridge (Fig. 4.3). It flows in an approximately southwestward direction for more than 560 km (350 miles) before merging with the Tennessee River near Kingston at Tennessee River Mile (TRM) 567.7.[14] The Clinch drainage basin encompasses an area of 11,400 km^2 (4413 sq miles) and has an average width of 30 km (18 miles). A dam constructed in 1963 at CRM 23.1 created the Melton Hill Reservoir, which establishes the eastern and southeastern boundaries of the Oak Ridge Reservation. This reservoir extends 71 river km (44 river miles) upstream to Eagle Bend, which lies about 13 km (8 miles) above Clinton, Tennessee. A volume of 118,600 acre-ft of water is impounded at the normal maximum elevation of 242 m (795 ft). The dam was constructed for power production, navigation, recreation, and some low-flow regulation, but it functions little in flood control.[14] Backwaters from the Watts Bar Dam (impounded in 1942) on the Tennessee River define part of the southwestern and western boundaries of the reservation and include the Clinch River and Poplar Creek in the vicinity of the ORGDP site (Fig. 4.4). The dam is located at TRM 529.8, about 61 km (38 miles) downstream from the mouth of the Clinch. Before the Melton Hill Reservoir existed, Watts Bar Dam regulated flows at the Oak Ridge Reservation to CRM 28. The dam's primary purposes are flood control, navigation, electric-power generation, and recreation. Minimum and maximum reservoir elevations, which are based on navigation and flood-control requirements, have been established. The minimum elevation recorded to date is 223.3 m (732.6 ft) (recorded on Mar. 20, 1945); the maximum elevation was measured at 227.0 m (745.4 ft) on Mar. 17, 1973. In the vicinity of the reservation, Watts Bar Reservoir ranges in width from 90 to 180 m (300 to 600 ft) and ranges in depth from 6.7 to 7.3 m (22 to 24 ft) at the full-pool elevation of 227 m (745 ft).[2,14]

Tributaries

The largest tributaries of the Clinch are the Powell and Emory rivers. The Powell arises northwest of the headwaters of the Clinch and flows parallel to it. The Powell receives water from a 2420-km^2 (938-sq-mile) area and joins the Clinch above Norris Dam at CRM 88.8. Northwest of the reservation, the Emory River drains a basin of 2240 km^2 (865 sq miles) before joining the Clinch at CRM 4.4 near Kingston.

The Oak Ridge Reservation proper is composed of a series of limited drainage basins through which small streams traverse and ultimately reach the Clinch River (Fig. 4.4). Poplar Creek is such a stream and it receives drainage from a 350-km^2 (136-sq-mile) area, including the northwestern sector of the reservation. The topographic relief of this basin exceeds that of all other water systems in the Oak Ridge area. Waters flow from the western half of the watershed (in the Cumberland Mountain section of the Appalachian Plateau Province) at elevations exceeding 975 m (3200 ft) to valleys in the Valley and Ridge Physiographic Unit at elevations of 226 m (741 ft) near the mouth. The creek flows through a basin that is about 65% wooded; the remainder is farmland. Some contamination occurs from the extensive surface coal mining that has occurred in the Cumberland Mountain district. The creek also receives municipal effluents from several small communities, including Oliver Springs.

The East Fork of Poplar Creek (Fig. 4.4) drains a 77-km^2 (29.8-sq-mile) roughly rectangular watershed, which is 15 km (9 miles) long and 5.5 km (3.5 miles) wide, and joins Poplar Creek at Poplar Creek Mile (PCM) 5.5. The East Fork originates on Chestnut Ridge, which separates this drainage area from the Whiteoak Creek catchment. The headwaters are collected in the Y-12 Plant area, where they receive wastes in the form of cooling-tower blowdown, waste-stream condensate, and process cooling water.[15] The creek then flows northwestward, roughly paralleling Tennessee State Highway 62 into the residential areas of Oak Ridge. A major contributor to the stream is the Oak Ridge west-end sewage plant which affords only primary treatment.

4.4.1.2 Hydrodynamics

The hydrology of the Clinch River–Poplar Creek system is highly complex due to the flow alterations induced by Melton Hill and Watts Bar dams. Thus, flows in the vicinity of the ORGDP site can be downstream, upstream, or zero. The construction of the Melton Hill Dam, in particular, has greatly changed the flow regime on the lower Clinch near ORGDP. Historical data indicate that no releases from Melton Hill Dam occur on about 50 days throughout the year, usually during

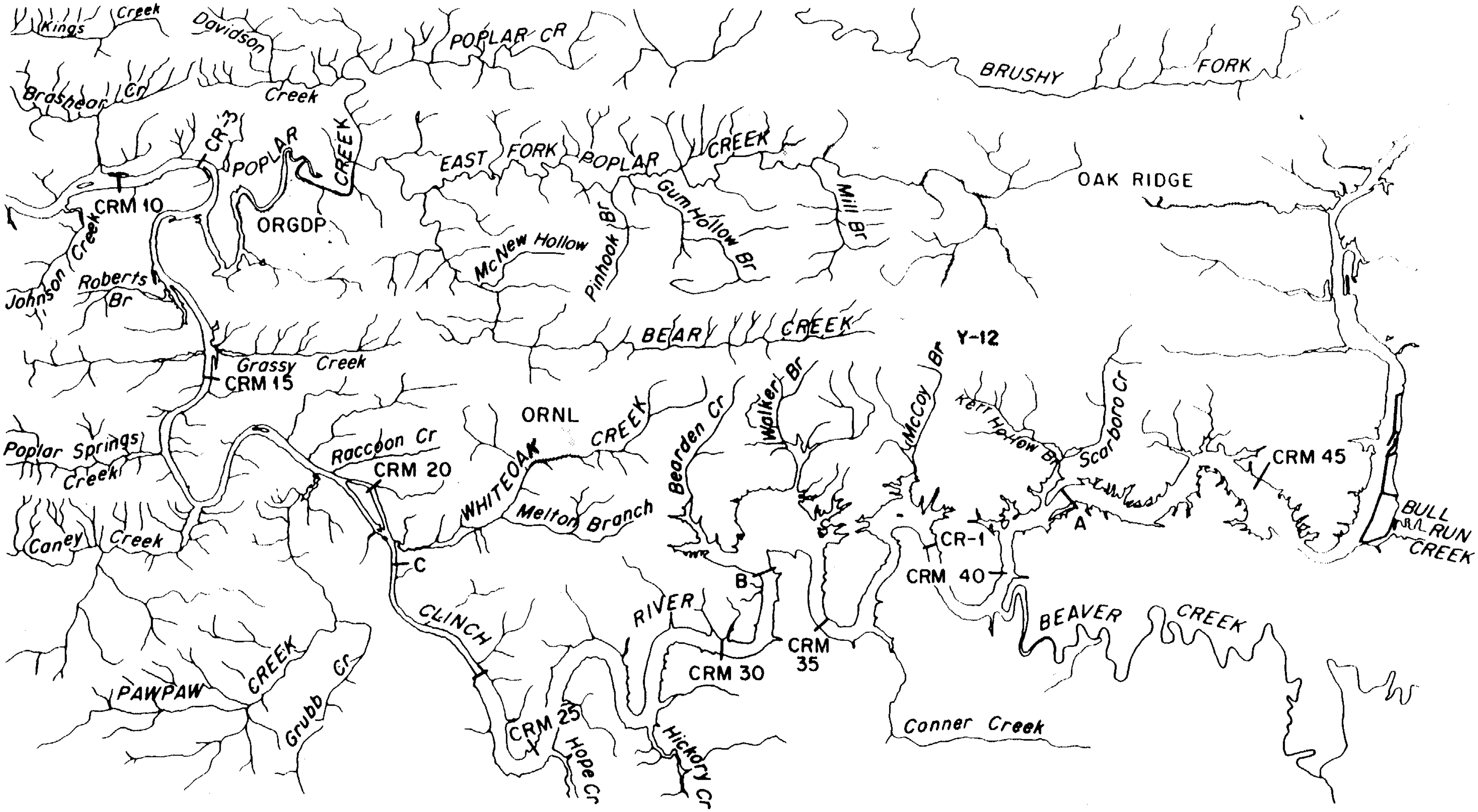

Fig. 4.4. Surface waters of the Oak Ridge area.

weekends when industrial power requirements are diminished. To sustain peak power demands, intermittent releases of 18,000 cfs frequently result on weekdays.[2] Pulsations in river flow are particularly pronounced in the late winter months, when reservoir levels have been raised because of heavy precipitation, and the requirements for flood control and hydroelectric power production are great.

Values for maximum, minimum, and average flows of the major Clinch River tributaries that drain the three DOE facility sites are given in Table 4.5. Additional data on flow characteristics of waters in the area can be obtained from refs. 14, 16, and 17 and from the U.S. Geological Survey's computerized water supply data (in EPA's STORET system) and TVA's annual reports on the operation of its reservoirs.

4.4.1.3 Water quality

Temperatures of the waterways adjoining the ORGDP site area depend somewhat on the effects induced by the release of hypolimnetic waters from Melton Hill Reservoir and the backup of epilimnetic waters from Watts Bar Reservoir. Thus, temperatures can vary greatly from day to day, especially during the summer. Table 4.6 gives representative temperature data for the Clinch River (near ORGDP) and the East Fork of Poplar Creek (about 3 miles upstream of the ORGDP site). Generally, the values are characteristic of submontane streams of the Southeast[18] — minimum temperatures are usually a few degrees above freezing and maximum temperatures are below 27°C (80°F). As such, these waters do not display as much natural seasonal temperature variation as do many streams in the United States. Temperature changes induced by reservoir outflow regulation are profound, however, and can affect certain of the aquatic biota. For example, curtailed releases from impoundments during the summer often put stress on cold-adapted biota that inhabit tailraces.[19]

Several surveys on water chemistry in the ORGDP vicinity have been conducted. Personnel from ORGDP routinely collect samples from stations on the Clinch River and Poplar Creek (Fig. 2.14), and studies have been conducted in support of the impact evaluation of proposed nearby facilities (the Clinch River Breeder Reactor Plant; the Exxon Fuel Reprocessing Plant).

The impacts of chemical discharges from ORGDP on water quality and water use are discussed in Sects. 5.3.3 and 5.3.4; the resultant impact on aquatic biota is treated in Sect. 5.2.2. The composition of the effluent streams is detailed in Tables 2.8 through 2.14. The six major chemical discharge points and two sanitary waste release locations are shown in Fig. 2.1.

Representative water quality analysis data are found in Tables 4.7 and 4.8. Duplicative data (i.e., from more than one study at a similar site) are found in ref. 15. Data obtained by different studies are similar for most of the parameters; important exceptions are noted below. Reference 15 contains a more complete discussion of the differences which occur. Generally, disparities can be attributed to one or more of the following: (1) differences in sampling and/or analytical technique; (2) subtle differences in sampling locations; (3) a difference in the time of sample collection (i.e., seasonal or yearly).

Clinch River and Poplar Creek can be characterized chemically as moderately hard bodies of water whose principal cation is calcium and whose anionic composition is dominated by bicarbonate and carbonate. As a result, these waters are well buffered; the pH is slightly alkaline and seldom varies more than 1 pH unit (Table 4.7).

Dissolved oxygen (DO) levels in the Clinch River approximate 6.0 mg/liter or greater year-round and vary little with depth, reflecting the well-mixed nature of the water column.[14] Values for BOD_5 are nearly always less than 3.5 mg/liter in the Clinch (Table 4.8), indicating relatively low degradable carbon levels. Recent data for DO and BOD are not available for Poplar Creek.

Nitrogen and phosphorus levels vary greatly in the Clinch River and Poplar Creek; the highest concentrations are generally found in the spring when the waters display moderately high fertility (Tables 4.7 and 4.8). Values for the principal nitrogen compounds (NO_2^-, NO_3^-, NH_3) varied widely among three major studies (for stations in close proximity to one another), and the cause of the discrepancy is unknown. Since these compounds are apparently not released from any nearby effluent discharge points (Sect. 2.2.3.3; also, ref. 15) the discrepancies may be due primarily to a difference in analytical methods.

Table 4.5. Flow characteristics of some of the major Clinch River tributaries on the Oak Ridge Reservation

	Discharge (cfs)			Period of record
	Maximum (Date)	Minimum (Date)	Average	
Melton Branch				
MBM 0.1	242 (3/11/62)	0 (9/2/62)	2.50	1955–1963
Whiteoak Creek				
WOCM 1.65	642 (8/30/50)	0 (9/16/61)	9.62	1950–1953 1955–1963
WOCM 0.6	669 (12/29/54)	0 (During power from Melton Hill Dam)	13.5	1950–1952 1955–1963
East Fork of Poplar Creek				
EFPCM 3.3	2610 (7/6/67)	13 (8/16/69)	48.3	1960–1970
Bear Creek				
BCM 0.8	594 (3/12/63)	0.50 (8/12–14/62)		
Poplar Creek				
Mouth	6350 (3/12/63)	5.0 (10/27/63)	165	1961–1965

Table 4.6. Representative midstream water temperature data for the Clinch River and the East Fork of Poplar Creek

	Temperature [°C (°F)]		
	Maximum	Minimum	Average
	Clinch River[a]		
January	12.2 (54)	8.9 (48)	10.6 (51)
February	10.6 (51)	7.8 (46)	8.9 (48)
March	12.2 (54)	9.4 (49)	10.6 (51)
April	17.2 (63)	11.1 (52)	14.4 (58)
May	17.8 (64)	15.0 (59)	16.1 (61)
June	20.6 (69)	16.7 (62)	18.9 (66)
July	23.3 (74)	19.4 (67)	21.7 (71)
August	23.9 (75)	21.1 (70)	22.2 (72)
September	22.2 (72)	20.0 (68)	21.7 (71)
October	20.6 (69)	16.1 (61)	19.4 (67)
November	17.8 (64)	11.7 (53)	15.0 (59)
December	13.9 (57)	10.0 (50)	12.2 (54)
	East Fork of Poplar Creek[b]		
January	8.9 (48)	4.4 (40)	7.2 (45)
February	8.9 (48)	6.7 (44)	7.8 (46)
March	13.9 (57)	7.8 (46)	11.1 (52)
April	19.4 (67)	10.0 (50)	15.6 (60)
May	21.1 (70)	15.0 (59)	18.3 (65)
June	24.4 (76)	17.8 (64)	21.7 (71)
July	23.9 (75)	19.4 (67)	22.2 (72)
August	24.4 (76)	18.9 (66)	22.8 (73)
September	23.9 (75)	16.7 (62)	21.1 (70)
October	21.7 (71)	12.8 (55)	16.1 (61)
November	18.3 (65)	7.2 (45)	14.4 (58)
December	13.3 (56)	5.6 (42)	10.0 (50)

[a] Near ORGDP, 1972.
[b] At EFPCM 3.3, 1964.

Table 4.7. Water quality data for 19 parameters measured at Poplar Creek and Clinch River stations[a,b]

Parameter (Detection limit)	Mean annual concentration[c] and range (in parentheses) (mg/liter)					
	West Fork (PCM 6.9)	K-1710 (PCM 5.3)	K-716 (PCM 0.3)	K-1513 (CRM 14.4)	K-901 (CRM 11.6)	Clinch River (CRM 9.8)
Ammonia (0.01, 0.2)[d]	<0.10 (<0.01–0.21)	0.13 (<0.01–0.24)	0.14 (<0.01–0.38)	<0.10 (<0.01–0.2)	0.10 (<0.01– <0.2)	<0.10 (<0.01–0.23)
Arsenic (0.01)	<0.01 (<0.01–0.02)	<0.01 (<0.01–0.03)	<0.01 (<0.01–0.02)	<0.01 (<0.01–0.03)	<0.01 (<0.01–0.02)	<0.01 (<0.01–0.03)
Cadmium (0.005)	<0.005 (all <0.005)	<0.005 (<0.005–0.006)	<0.005 (all <0.005)	<0.005 (all <0.005)	<0.005 (all <0.005)	<0.005 (<0.005–0.007)
Chromium, total (0.005)	0.006 (<0.005–0.01)	0.007 (<0.005–0.016)	0.014 (0.008–0.022)	0.007 (<0.005–0.015)	0.007 (<0.005–0.015)	0.005 (<0.005–0.008)
COD (2, 5)[e]	8 (<5–13)	7 (<5–14)	10 (<5–14)	5 (<5–10)	6 (<2–13)	5 (<2–10)
Copper (0.005)	0.014 (<0.005–0.048)	0.017 (<0.005–0.059)	0.016 (<0.005–0.08)	0.026 (<0.005–0.029)	0.013 (<0.005–0.06)	0.014 (<0.005–0.073)
Cyanide (0.0005, 0.002)[f]	0.0025 (<0.005–0.013)	0.0021 (0.0006–0.005)	0.0022 (<0.0005–0.005)	0.0016 (<0.0005–0.003)	<0.0019 (<0.0005–0.005)	0.0021 (<0.0007–0.0005)
Fluoride (0.1)	<0.010 (<0.1–0.13)	0.23 (<0.1–0.44)	0.22 (<0.1–0.4)	<0.11 (<0.1–0.17)	<0.1 (<0.1–0.1)	<0.11 (<0.1–0.2)
Lead (0.005, 0.01)[g]	<0.010 (<0.005–0.02)	0.034 (0.006–0.3)	<0.010 (<0.005–0.019)	<0.009 (<0.005–0.014)	<0.010 (<0.005–0.02)	<0.010 (<0.005–0.02)
Manganese (0.005)	0.158 (0.019–0.311)	0.080 (0.025–0.198)	0.122 (0.04–0.173)	0.035 (<0.005–0.3)	0.036 (0.01–0.48)	0.063 (0.007–0.28)
Mercury (0.001)	<0.001 (<0.001–0.002)	<0.001 (<0.001–0.001)	<0.001 (<0.001–0.001)	<0.001 (all <0.001)	<0.001 (<0.001–0.001)	<0.001 (<0.001–0.003)
Nickel (0.005)	0.020 (<0.005–0.112)	0.019 (<0.005–0.08)	0.015 (0.002–0.031)	0.011 (<0.005–0.026)	0.013 (<0.005–0.027)	0.009 (<0.005–0.018)
Nitrates (0.01)	2.13 (0.04–3.54)	2.68 (0.28–6.20)	3.82 (<0.01–5.49)	2.99 (1.72–4.25)	4.32 (1.45–14.7)	2.54 (0.35–4.96)
(pH, units	N.A.[h]	7.0 (6.0–8.3)	7.4 (7.0–8.2)	7.8 (7.1–8.1)	7.4 (6.9–7.8)	N.A.)
Sodium	4.17 (2.5–5.79)	5.07 (3.02–7.81)	5.89 (1.8–9.64)	3.12 (2.5–3.88)	3.34 (2.68–4.00)	3.19 (1.95–4.2)
Sulfates	43 (25–53)	34 (21–50)	34 (15–45)	23 (14–40)	27 (15–50)	24 (13–45)
Total dissolved solids	189 (40–330)	195 (114–294)	179 (98–244)	160 (118–278)	168 (114–202)	159 (90–218)
Total suspended solids (5)	26 (<5–67)	20 (<5–74)	21 (<5–43)	11 (<5–32)	19 (<5–74)	16 (<5–34)
Zinc	0.017 (0.005–0.053)	0.025 (0.008–0.51)	0.028 (0.009–0.059)	0.050 (0.016–0.133)	0.020 (0.006–0.05)	0.017 (0.005–0.05)
Uranium				0.003		

[a]Mean values were calculated from monthly data collected from April 1977 to March 1978.

[b]Station locations are shown in Fig. 2.14.

[c]Because "less than" signs were ignored in these computations, the means are biased and somewhat conservative. An annual mean was reported as less than the detection limit if more than half the monthly concentrations reported for a parameter were below it.

[d]Detection limit was 0.01 mg/liter for April through September and March samples and 0.2 mg/liter for October through February samples.

[e]Detection limit was 2 mg/liter for April through September samples and 5 mg/liter for October through March samples.

[f]Detection limit was 0.0005 mg/liter for April through September and March samples and 0.002 mg/liter for October through February samples.

[g]Detection limit was 0.005 mg/liter for June, November, and January samples and 0.01 mg/liter for the other nine samples.

[h]N.A. = data not available.

Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Table 4.8. Water quality data for selected parameters measured at three Clinch River stations[a,b] upstream of ORGDP sanitary water intake

Parameter	Concentration (mg/liter)								
	Transect 1, station 5			Transect 4, station 3			Transect 5, station 5		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Total alkalinity, as $CaCO_3$	96	76	114	98	76	116	93	76	106
Hardness (total), as $CaCO_3$	112	96	136	115	88	138	111	82	136
Calcium[c]	N.A.[d]	N.A.	N.A.	33.5	24.0	43.0	N.A.	N.A.	N.A.
Magnesium[c]	N.A.	N.A.	N.A.	7.8	7.0	8.6	N.A.	N.A.	N.A.
Iron (total)[c]	N.A.	N.A.	N.A.	0.38	0.08	0.68	N.A.	N.A.	N.A.
Chloride	5.0	2.6	13.0	4.7	2.0	11.0	4.6	1.0	10.0
Potassium	1.4	1.1	1.7	1.4	1.1	1.[illegible]	1.3	1.1	1.6
BOD	2.1	0.3	6.0	1.8	0.9	3.0	2.2	<1.0	3.4
Total organic carbon	4.0	1.0	10.0	4.5	1.0	9.0	3.2	1.0	6.0
Phosphorus[e]									
Ortho PO_4^{3-}-P	0.026	<0.003	0.120	0.013	<0.003	0.060	0.015	<0.003	0.100
Total PO_4^{3-}-P	0.041	<0.003	0.130	0.049	<0.003	0.230	0.064	<0.003	0.350
Nitrogen[e]									
NO_2^--N	0.010	<0.001	0.068	0.010	<0.001	0.062	0.001	<0.001	0.065
NO_3^--N	0.010	<0.001	0.068	0.010	<0.001	0.062	0.001	<0.001	0.065
NH_3-N	0.2	0.1	0.5	0.3	0.1	0.5	0.2	0.1	0.5

[a]Data were collected from March 1974 through April 1975.

[b]*Transect and station locations are shown in Fig. 1.4-1 of source note 2 (see below)*

[c]Samples were only taken in March and September 1974 at transect 4, station 3.

[d]N.A. = data not available.

[e]For calculation of mean values, levels under the limit of detection were considered to represent one-half the detection limit value.

Sources:

1. Project Management Corporation and the Tennessee Valley Authority, *Clinch River Breeder Reactor Project Environmental Report*, Construction Permit Stage, Docket No. 50-537, Apr. 2, 1975, Tables 2.7-32 and 2.7-35.

2. James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Ammonia concentrations in the Clinch River and Poplar Creek at times exceed recommended levels for the protection of aquatic biota. The presence of the toxic unionized form depends strongly on pH; little is present at pH values below 7. At pH 8.3 (the maximum recorded in the vicinity; see Table 4.7), 10% of the ammonia is NH_3.[20] Under such conditions, the criterion for the protection of aquatic biota[21] of 0.02 mg/liter would be exceeded at most of the stations listed in Table 4.7. The implications of this for the aquatic biota, as well as the effects of other potential toxicants found in the area's waters, are discussed in Sects. 5.2.2, 5.3.3, and 5.3.4.

Mercury in the water was found in concentrations significantly above background (Table 4.7) at all area sites (Fig. 2.14) sampled during the ORGDP monitoring program.[15] Levels of up to 0.003 mg/liter were recorded; background concentrations in this area should not exceed 6×10^{-5} mg/liter (0.06 µg/liter).[22] The mean concentrations at all the stations are below the detection limit used in the available studies (0.001 mg/liter), but this level is above the current standard for the protection of aquatic biota — 5×10^{-5} mg/liter (0.05 µg/liter).[21] Thus, average concentrations at the sampling stations may exceed the water quality standard.

Of the eight other heavy metals analyzed in the available studies, only zinc was found to occur in concentrations potentially harmful to biota (Sects. [illegible] and 5.3.3).

PCB concentrations were determined at five locations in Poplar Creek and the Clinch River; all values were below the 0.0005-μg/liter limit of detection.[15] Concentrations below 0.001 μg/liter are not believed to significantly affect aquatic biota.[21]

4.4.1.4 Sediment quality

Several studies of heavy-metal concentrations in sediments were conducted in the vicinity of ORGDP.[15] Table 4.9 summarizes the data from the most complete evaluation. (The sampling locations are shown in Fig. 4.5.) The data for many of the elements display a high degree of variability — both in differences among sampling sites and among sampling dates. For some of the parameters, analytical methods were changed during the course of the investigation, thereby potentially altering the precision and accuracy of the determinations. For comparison, a compilation of published values representative of largely uncontaminated areas is provided in Table 4.10. Likewise, Table 4.11 lists mercury concentrations in various sediments, from both contaminated and relatively pristine locations.

Cadmium levels in the sediments near ORGDP may be elevated above concentrations expected in an uncontaminated environment (cf. Tables 4.9 and 4.10), but the precise concentration of cadmium cannot be determined from the data because the detection limit of the analytical method used was 5 μg/g dry weight. Chromium concentrations appear to be elevated (at least, at some sampling locations), as do levels of the other heavy metals measured (copper, lead, manganese, mercury, nickel, and zinc). All these metals currently are discharged at one or more locations at ORGDP (Sect. 2.2.3.3). The mercury values are particularly noteworthy — some of the concentrations found are up to five orders of magnitude greater than those found in relatively pristine areas and up to two orders of magnitude greater than values determined for other contaminated locations (cf. Tables 4.9, 4.10, and 4.11). For example, the highest reading, from a Poplar Creek sample, was 307 μg/g (dry weight); for comparison, an uncontaminated British stream was 0.03 to 0.17 μg/g, and the heavily polluted Rhine River was 6.90 μg/g. More than 80% of all sediment samples from the mouth of Poplar Creek to its confluence with the East Fork of Poplar Creek had mercury levels >1.0 μg/g; more than 33% had values >10 μg/g. However, sediment concentrations varied greatly among sampling sites on a particular sample day and among sampling dates at a given site. Sections 5.2.2 and 5.3.3 contain additional information on mercury distribution, as well as a discussion of the potential impacts of elevated mercury levels. It is believed that the source of current mercury levels in the ORGDP area of Poplar Creek results from past operations at Y-12.[23]

Data on sediment concentrations of polychlorinated biphenyls (PCBs) indicate that levels in Poplar Creek are higher than in the Clinch River. A 1974 study of six stations on Poplar Creek revealed levels ranging from 6 to 15 μg/g ($\overline{X}$ = 11 μg/g), although another survey (of different stations) reported concentrations that were roughly an order of magnitude smaller.[15] In comparison, nearly all values for Clinch River sediment samples were <0.1 μg/g, and a few were <0.001 μg/g. PCB effects on biota are discussed in Sect. 5.2.2.

4.4.1.5 Water use

The ORGDP currently takes about 12 Mgd (19 cfs) of water from the Clinch River for makeup cooling water; this will be increased to about 20 Mgd (31 cfs) by 1984 (Sect. 2.2.3.3). The sanitary water demand is about 4 Mgd (6 cfs) and is not expected to increase substantially over the next few years. These withdrawals, taken at Clinch River Mile (CRM) 11.5 and 14.4, respectively, would be (in 1984) only about 6% of the seven-day, ten-year low flow and only about 1% of the average flow. Additionally, about 25% of the water will be returned to the river as treated sewage or as blowdown water. Currently, no withdrawals are made from Poplar Creek, although several effluent release points are located on it (Sect. 5.3.3).

Other industries and municipalities in the vicinity of ORGDP that use water from the Clinch River include DOE Oak Ridge Operations (ORNL and Y-12 Plant) and the city of Oak Ridge (22 Mgd at CRM 41.5) and the TVA Bull Run Steam Plant (572 Mgd at CRM 47.6).[2] All are upstream from ORGDP.

The Clinch River (including Melton Hill and Watts Bar reservoirs) adjacent to the reservation is a component of the Inland Waterway System, which allows commercial navigation to the Gulf of Mexico. Commercial traffic locked through Melton Hill Dam amounted to 3000 tons (2720 metric tons) in 1975. In 1974, 631 recreational craft passed through the Melton Hill locks.[14]

Table 4.9. Heavy metals in sediments from various sites in Poplar Creek and the Clinch River

Sampling station[a]	Concentration[b] and range (in parentheses) (μg/g dry weight)							
	Cadmium	Chromium	Copper	Lead	Manganese	Mercury	Nickel	Zinc
1	All <5	54 ± 25.6 (50–92)	23 ± 12.3 (13–40)	36 ± 36.7 (10–90)	1290 ± 1060 (230–2290)	0.1 ± 0.1 (<0.1–0.4)	179 ± 281 (27–600)	75 ± 37.8 (28–120)
2	All <5	66 ± 33.6 (20–115)	52 ± 38.3 (20–116)	36 ± 30.4 (20–90)	330 ± 142.0 (130–500)	11.5 ± 18.1 (<0.1–43.0)	241 ± 259 (30–660)	112 ± 84.1 (30–250)
3	3 ± 4.2 (<5–10)	96 ± 45.8 (60–170)	51 ± 35.2 (16–90)	113 ± 88.8 (24–250)	464 ± 255 (170–775)	12.2 ± 7.4 (2.0–18.8)	219 ± 316 (48–780)	123 ± 48.4 (54–175)
4	All <5	127 ± 42.9 (77–180)	62 ± 32.3 (17–104)	94 ± 118 (20–300)	526 ± 235 (130–700)	6.7 ± 5.2 (2.0–12.5)	398 ± 537 (42–1300)	132 ± 51.9 (40–165)
5	All <5	117 ± 82.8 (17–200)	51 ± 38.3 (5–100)	47 ± 21.4 (21–80)	650 ± 414 (20–1130)	3.6 ± 4.1 (<0.1–10.0)	181 ± 266 (28–648)	124 ± 88.6 (8–220)
6	All <5	192 ± 98.2 (83–320)	65 ± 39.2 (20–120)	105 ± 167 (20–400)	365 ± 184 (120–394)	18.4 ± 18.6 (2.0–39.0)	224 ± 210 (70–580)	134 ± 73.5 (62–250)
7	2 ± 4.4 (<5–10)	105 ± 74.4 (42–215)	42 ± 27.6 (10–76)	41 ± 24.7 (10–75)	484 ± 239 (270–871)	28.7 ± 54.0 (<0.2–125.0)	149 ± 198 (40–500)	136 ± 85.0 (25–223)
8	All <5	84 ± 35.0 (31–125)	117 ± 143 (7–355)	41 ± 24.7 (10–75)	547 ± 377 (50–1090)	1.0 ± 1.2 (<0.2–3.0)	291 ± 300 (35–700)	128 ± 33.9 (100–180)
9	All <5	86 ± 42.3 (43–143)	43 ± 39 (16–95)	36 ± 22.9 (20–70)	577 ± 441 (160–1200)	9.3 ± 9.0 (0.6–21.5)	117 ± 77.2 (39–200)	103 ± 72.3 (26–200)
10	3 ± 4.2 (<5–10)	119 ± 86.7 (42–240)	44 ± 27.9 (11–70)	70 ± 75.2 (20–200)	681 ± 253 (440–1000)	11.1 ± 11.3 (<0.2–30.0)	236 ± 251 (43–600)	127 ± 77.7 (21–200)
11	All <5	107 ± 59.2 (45–185)	56 ± 34.2 (11–90)	55 ± 27.4 (24–90)	543 ± 348 (100–940)	7.0 ± 7.9 (0.8–20.0)	165 ± 163 (43–445)	140 ± 71.1 (27–200)
12	All <5	53 ± 28.6 (19–90)	40 ± 21.4 (14–70)	34 ± 32.4 (10–90)	554 ± 478 (20–1070)	3.4 ± 4.4 (<0.1–10.0)	198 ± 220 (30–500)	97 ± 69.6 (5–200)
13	All <5	72 ± 21.3 (41–100)	75 ± 58.8 (8–150)	33 ± 13.8 (10–50)	466 ± 333 (80–835)	2.5 ± 3.1 (<0.1–6.5)	198 ± 191 (38–500)	107 ± 60.0 (20–175)
14	All <5	90 ± 27.6 (49–110)	79 ± 67.2 (23–175)	35 ± 6.1 (29–40)	532 ± 372 (150–970)	102 ± 144 (<0.2–307)	127 ± 51.0 (169–170)	94 ± 70.6 (9–170)
15	2 ± 4.4 (<5–10)	108 ± 109 (45–300)	59 ± 66.0 (12–175)	32 ± 14.6 (10–48)	709 ± 520 (150–1400)	2.2 ± 3.2 (<0.2–7.8)	130 ± 121 (43–334)	98 ± 70.8 (22–182)
16	All <5	339 ± 172 (140–537)	174 ± 20.8 (153–200)	45 ± 21.2 (25–73)	526 ± 184 (270–700)	6.4 ± 9.7 (1.0–21.0)	351 ± 228 (175–680)	148 ± 28.0 (120–180)
17	All <5	262 ± 198 (56–570)	238 ± 140 (46–430)	37 ± 20.3 (20–66)	492 ± 211 (210–780)	7.2 ± 3.7 (2.0–11.0)	812 ± 533 (46–1500)	223 ± 132 (43–410)
18	2 ± 4.4 (<5–10)	65 ± 15.4 (45–88)	37 ± 13.0 (26–50)	35 ± 7.0 (27–44)	666 ± 222 (430–1000)	9.6 ± 13.0 (1.0–32.0)	119 ± 114 (56–322)	84 ± 22.0 (50–106)
19	All <5	86 ± 55.3 (50–184)	82 ± 68.4 (31–200)	37 ± 17.7 (20–60)	718 ± 536 (70–1300)	22.8 ± 23.6 (<0.1–62.0)	116 ± 71.9 (50–226)	92 ± 35.9 (37–130)
20	All <5	37 ± 15.6 (26–48)	16 ± 10.6 (8–23)	37 ± 13.4 (28–47)	406 ± 320 (180–632)	0.4 ± 0.1 (0.3–0.4)	55 ± 26.2 (36–73)	45 ± 43.1 (14–75)
Overall mean	1	113	70	50	576	13.3	225	116
Overall range	<5–10	17–570	5–430	10–400	20–2290	0.1–307	27–1500	5–410

[a] Locations are shown in Fig. 4.5.

[b] Values given were obtained during 1975–1977; in most cases, samples were taken in July 1975, 1976, and 1977 and November 1976 and 1977.

Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

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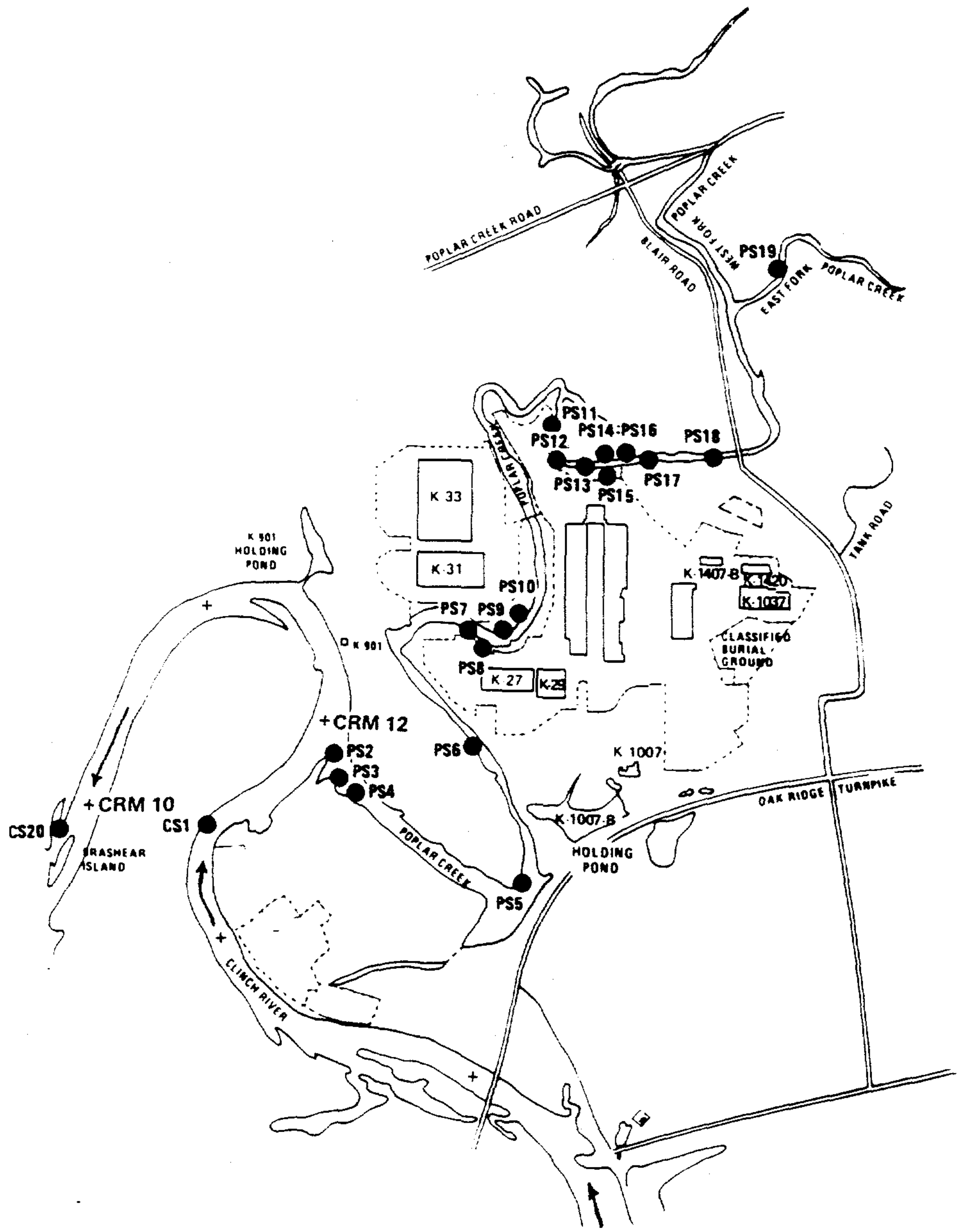

Fig. 4.5. Surface-water sediment sampling stations surveyed in July and November of 1976 and 1977 for aluminum, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc. Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant,* ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Recreational use of the waters in the Oak Ridge area is heavy. Although no quantification of the activities is available, swimming, fishing, and localized recreational boating are very popular. The Clinch River and its reservoirs are primarily used for these sports, but smaller tributaries (such as Poplar Creek) are frequently fished (Fig. 2.14).

4.4.2 Groundwater

The migration of radioactive or other contaminants by groundwater movement is an environmental concern resulting from the operation of ORGDP. Under certain conditions, transport over large distances can occur in groundwater, and groundwater can also become a means by which contaminants are transmitted to surface streams. The three basic parameters that affect groundwater movement are hydraulic gradient, permeability, and aquifer length.

Table 4.10. Heavy metal concentrations in aquatic sediments from relatively uncontaminated areas

Location	Concentration [µg/g (dry weight)]								Source
	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Zn	
Pennsylvania stream	0.05–0.39	N.A.[a]	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	1
Willamette River (Oregon)	0.5–60	55–135	5–30	5–100	N.A.	0.08–0.80	N.A.	60–225	1
Solway (U.K.)	0.7–1.3	1.6–8.4	1.9–17	11.5–34.1	3.8–1160	0.03–0.17	6.1–34.5	25–98	1
Atlantic Ocean Bermuda rise (deep sea)	N.A.	N.A.	77	92	3170	N.A.	112	168	1
Six Adirondack lakes (average, standard deviation, and range)	0.1 ± 0.09 (0.1–0.3)	0.5 ± 0.33 (0.1–1.3)	0.6 ± 0.66 (0.1–2.1)	N.A.	N.A.	N.A.	0.9 ± 0.81 (0.1–2.9)	7.6 ± 8.1 (1.0–37.3)	2
Ottawa River (Canada)	N.A.	22	28	26	118	0.28	22	84	3
Lake Mary (northern Wisconsin)	2.4	1.0	38	3	N.A.	N.A.	14	12	4

[a]N.A. = data not available.

Sources:

1. H. V. Leland et al., "Heavy Metals and Related Elements (A Review)," *J. Water Pollut. Contr. Fed.* 50, 1469–1514 (1978).
2. S. L. Williams, D. B. Aulenbach, and N. L. Clesceri, "Distribution of Metals in Lake Sediments of the Adirondack Region of New York State," pp. 153–66 in H. Drucker and R. E. Wildung, eds., *Biological Implications of Metals in the Environment, Proceedings of the 15th Annual Hanford Life Sciences Symposium*, ERDA, Technical Information Center, 1977.
3. B. G. Oliver, "Heavy Metal Levels of Ottawa and Rideau River Sediments," *Environ. Sci. Technol.* 7, 135–37 (1973).
4. I. K. Iskandar and D. R. Keeney, "Concentration of Heavy Metals in Sediment Cores from Selected Wisconsin Lakes," *Environ. Sci. Technol.* 8, 165–70 (1974).

Table 4.11. Mercury concentrations in various sediments

Location	Sediment concentration [µg/g (dry weight)]	
	Average	Range
San Francisco Bay	0.29	0.02–2.00
Southern Lake Michigan	0.14	0.03–0.38
Lake Wisconsin	0.15	0.01–0.35
Rhine River	6.90	1.2–23.3
Thames River	1.80	1.0–3.3
James, York, and Rappahannock estuaries	1.14	0.4–2.6
La Jolla, California	0.34	0.02–1.0
Le Havre River and estuary	0.34	0.09–1.06
Connecticut Harbor	0.83	0.04–2.57
Mississippi River	0.33	0.07–1.10
Mobile River estuary	0.37	0.03–6.14
Everglades	0.60	0.04–1.86
Bellingham Bay	4.27	0.8–10.7
Georgia salt marsh	0.11	0.05–0.35

Source: S. E. Lindberg, A. W. Andren, and R. C. Harriss, "Geochemistry of Mercury in the Estuarine Environment," pp. 64–107 in L. E. Cromin, ed., *Estuarine Research. Vol. 1. Chemistry, Biology and the Estuarine System*, Academic Press, New York, 1975, Table 8.

The height of a column of water above the local baseline provides the force that moves groundwater through soil and permeable rocks. In a flat, unconfined system, the hydraulic gradient is normally very slight, consisting of a slight elevation over the point of highest infiltration. Topography has a profound local effect on hydraulic gradients in areas with significant relief, such as the Poplar Creek Basin. Ridges that are highly permeable near the crest or the upper slopes cause water to accumulate within the ridge. In the Valley and Ridge Province, the hydraulic gradient is also affected by structural and stratigraphic features. Strata are typically dipping to the southeast at a relatively steep angle. Permeability is almost invariably higher parallel to the bedding planes than across them. Water infiltrating at the top of the ridge flows into the ridge along the bedding planes and accumulates faster than it discharges, since it must cross the bedding planes to flow out at the foot of the ridge.

Permeability is a complex feature of groundwater systems. Generally, it is a function of the average volume of effective (i.e., connected) pore space in an aquifer. For particular aquifer cross sections (perpendicular to flow), permeability can vary widely. An aquifer with generally low permeability may have localized zones such as solution channels or fracture systems with extremely high permeabilities. The relative size of these zones can also vary from a few centimeters to hundreds of meters. For a given hydraulic gradient, the rate at which a particular cross-sectional area is able to transmit water is called the hydraulic conductivity.

Frictional forces retard flow and accumulate with distance. This effect reaches a steady state over relatively long distances, but, for relatively short flow paths, the velocity decreases directly with increasing distance.

Investigations of groundwater conditions at the ORGDP site (Sect. 2.2.3.3) were started too late to be of use in this report. The limited data (initial well samples taken late spring 1979) indicated that apparently no problem exists from the present land disposal of solid wastes. Groundwater conditions, therefore, are mainly inferred from regional studies.[24-29] McMaster's[10] description of the structure and stratigraphy of the Oak Ridge area (Appendix A) leads to the conclusion that conditions exist for artesian flow at the base of Blackoak Ridge, where the Knox Dolomite is in contact with the Chickamauga Limestone. This is believed to be the source of the numerous springs found in East Fork Valley northeast of ORGDP, near Oliver Springs.[1] This contact runs through the northwest corner of the site (Fig. 4.2). Springs flowing from the Chickamauga Limestone are not found in East Fork Valley, as would be expected of a formation with thinly bedded and silty lithology.

Other evidence of the low hydraulic conductivity of the Chickamauga is given by the low-flow characteristics of streams in the area. Stream channels that have a large portion of their drainage areas underlain by the Knox have sustained high flows in dry weather, whereas stream basins underlain by Chickamauga have not.[24] This indicates that a substantial portion of stream discharge is supplied by groundwater from the Knox, but not the Chickamauga. Caverns and sink holes caused by groundwater movement are commonly found in exposures of the Knox Dolomite.[10] Solution channels are also found in the Chickamauga Limestone, but they are much smaller[24] and do not appear to significantly affect hydraulic conductivity in this area.

In terms of the specific aquifer properties at the ORGDP site, the general hydraulic characteristics of the Chickamauga are not sufficiently evident to conclude that low groundwater flow rates through the site are likely. The combination of fault zones and formation contacts within the site area (Sect. 4.3) may provide groundwater channels that alter the generally low hydraulic conductivity predicted for the Chickamauga. Local conditions could easily create enlarged solution channels in the Chickamauga, which could connect to even larger channels in the nearby Knox Dolomite. Springs in the upper East Fork Valley indicate that flow rates of up to 3.8 cfs are possible.[24]

Soil cover is important to the confinement of waterborne contaminants. The thickness and permeability of the soil cover can control the rate of recharge in underlying rocks and can absorb surface contaminants. The Chickamauga, which underlies the largest part of the site area, has a characteristically impermeable clay residuum less than 3 m thick.[24] The Conasauga Shale underlying the southeastern portion of the site has a soil cover that is typically more hydraulically conductive than the parent rock. For this reason, groundwater normally moves in the soil cover and not the underlying bedrock. It should be pointed out, however, that most sites are extensively reworked during construction, often down to bedrock, and reworked soil is almost invariably more permeable than the original.

From the geology and topography of the site area, the flow pattern of groundwater can be expected to be generally at right angles to topographic contours, flowing down-slope from the flanks of the ridges, bending down East Fork Valley into Poplar Creek and the East Fork. The low point for the entire valley is the mouth of Poplar Creek. It is expected that any water flowing under the site or infiltrating the groundwater from the surface would discharge into Poplar Creek or the Clinch River a very short distance from ORGDP. The likelihood that contaminants in the soil on the site could bypass Poplar Creek or the Clinch River by groundwater transport is probably remote. How much of a particular release of contaminants would be retained by the soil and rock underlying the site, how rapidly it would reach the streams, and how far downstream it would travel are difficult to ascertain from the general information available. Because of the geologic structures within the site area and their potentially high hydraulic conductivities, it is quite possible that very little barrier exists between ORGDP and the streams. The quality of the barrier provided by the site can only be properly assessed by a detailed site survey and some specific subsurface information provided by boreholes. In addition to the hydraulic conductivity of the soil and underlying bedrock, chemical and mechanical storage coefficients, infiltration rates, and depth to groundwater must be determined.

4.5 METEOROLOGY

4.5.1 Regional

The climatology of the Oak Ridge area reflects primarily its topography. Because the "Great Valley" (which includes the Valley and Ridge Physiographic Province and the Tennessee River Basin) is nestled between two great mountain ranges, the Appalachians and the Cumberlands, its weather patterns are localized within the lowlands and are generally unlike those that occur in the more mountainous segments of the southeastern United States. Prevailing-wind regimes travel predominantly in a northeast-to-southwest line, both up- and down-valley, in alignment with the parallel ridges that were thrust-faulted in a similar direction. Intense, highly confined storms of short duration occur frequently within the area, especially at points of topographical discontinuity, because of the production of significant barometric gradients.

A climograph (plot of temperature vs precipitation) for the Oak Ridge area is given in Fig. 4.6.[30] Heavy precipitation occurs in both the winter and summer, whereas spring and autumn are comparatively dry. Only under unusual conditions is snowfall a significant portion of the precipitation. Average temperatures are in the moderate range, 5° to 27°C (40° to 80°F). Extreme temperatures, both hot and cold, are relatively uncommon because of the moderating influences of the adjacent mountain ranges.

Thornwaite[31] has developed a climatic classification scheme based on the water balance of different geographical regions. He classifies the Oak Ridge area as humid subtropical. Figure 4.7 is a graph of water flow as a function of season for such a climatic region; a soil-moisture capacity of 0.3 m (12 in.) is assumed. The dotted line slightly skewed to the later summer months represents the precipitation input which, as previously described, generally rises and declines in alternate quarters. The solid bell-shaped curve portrays the hydrological output which, in vegetated areas, is largely a function of plant metabolism and accompanying evapotranspiration losses. Obviously, plant photosynthetic activity will be at a maximum in summer months and at a minimum in winter months. This diagram indicates that the low frequency of precipitation during May and June may become critical for plant life. However, recharge by the frequent rainstorms that commonly occur in July and August is usually sufficient to overcome this drought stress and to produce conditions adequate for agriculture.

No unique climatic features differentiate weather on the Oak Ridge Reservation from other humid southern Appalachian regions.

4.5.2 Local

4.5.2.1 Meteorological stations

Before the Manhattan Engineering District's projects, no meteorological records were maintained in the Oak Ridge area. However, climatological data have been recorded in Knoxville since 1871 by the Signal Corps and later by the U.S. Weather Bureau, which was created in 1891. The major Knoxville office is now located at McGhee-Tyson Airport, about 37 km (23 miles) southeast of ORGDP.

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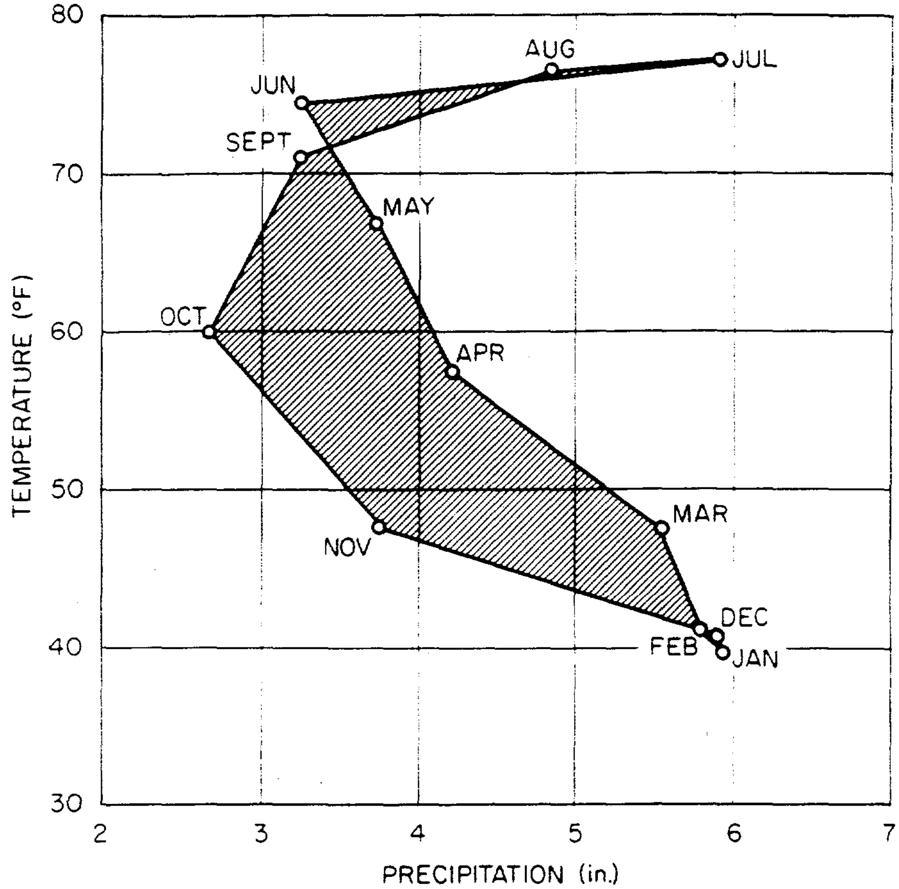

Fig. 4.6. Climograph of the Oak Ridge area. Source: J. W. Curlin and D. J. Nelson, *Walker Branch Watershed Project: Objectives, Facilities, and Ecological Characteristics*, ORNL/TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tenn., September 1968, p. 17.

The first weather-recording instrumentation on the Oak Ridge Reservation was installed to assist in monitoring airborne radioactivity at the Oak Ridge National Laboratory (ORNL) site in conjunction with the startup of the "Clinton pile" (now known as the Graphite Reactor). The Y-12 Plant and ORGDP stations were also created shortly after these two plants started operation. In 1947, the Oak Ridge stations were designated official U.S. Weather Bureau cooperative offices. Meteorological data from the city of Oak Ridge were incorporated into the program in 1948; a final recording facility was established in the late 1950s at the Tower Shielding Facility (TSF).

Table 4.12 describes the location and instrumentation of each of these weather stations. Weather records of the Oak Ridge Office of the U.S. Weather Bureau are now maintained by the National Oceanic and Atmospheric Administration's (NOAA) Atmospheric and Turbulence Diffusion Laboratory (ATDL) within the city of Oak Ridge.

Information on meteorological conditions at Oak Ridge is summarized in three reports. The U.S. Weather Bureau[32] made a detailed analysis of the parameters that affected Oak Ridge area weather from 1948 to 1952. In 1963, the analysis was updated by the supplemental report of Hilsmeier.[33] Climatological data obtained in the years 1951 to 1971 have been collected, but not summarized, in a recent ATDL publication.[34]

4.5.2.2 <u>Temperature</u>

Minimum, maximum, and average monthly temperatures calculated from data collected during the 1951 to 1971 period of record are given in Table 4.13. The daily temperatures, which are

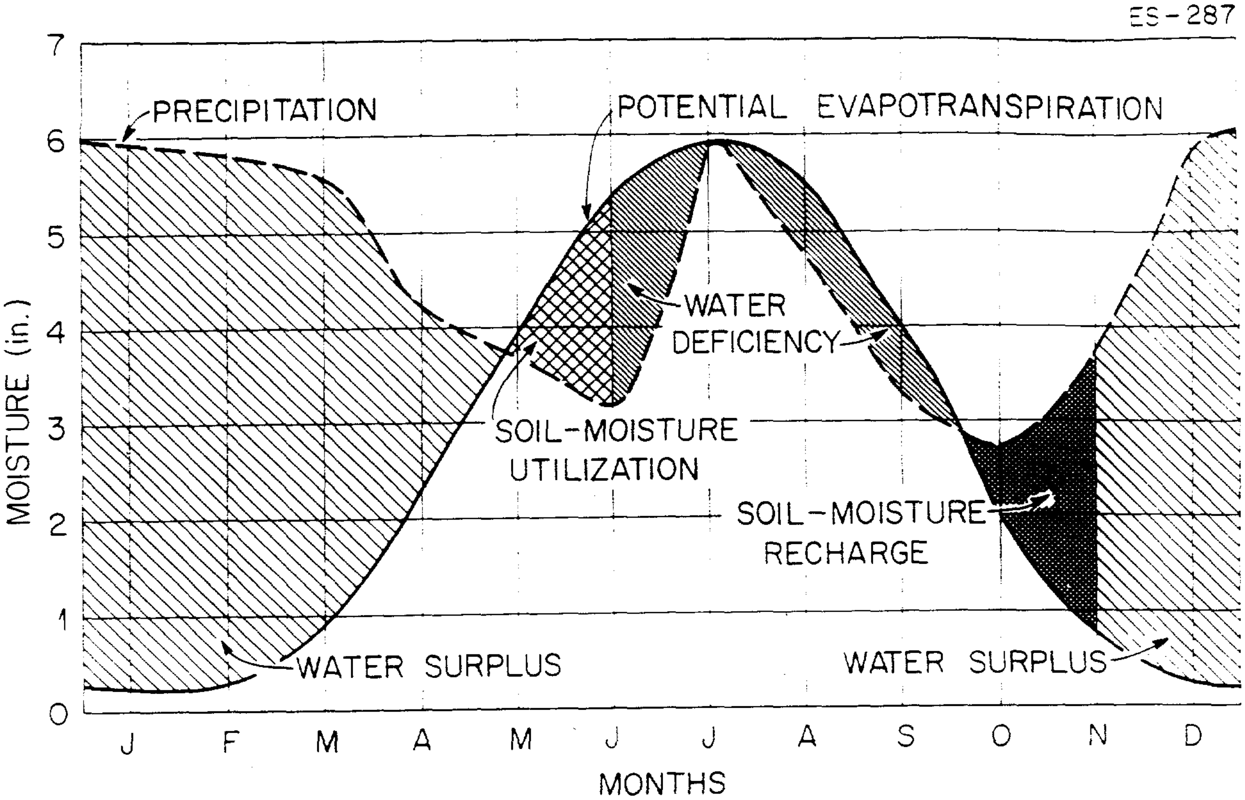

Fig. 4.7. Generalized water balance scheme for humid subtropical climatic regions such as the Oak Ridge area. Source: J. W. Curlin and D. J. Nelson, *Walker Branch Watershed Project: Objectives, Facilities, and Ecological Considerations*, ORNL/TM-2271, Oak Ridge National Laboratory, Oak Ridge, Tenn., September 1968, p. 18.

indicative of the temperatures of the Oak Ridge Reservation, range from a minimum of -22.8°C (-9°F) in January to a maximum of 40.6°C (105°F) in July, the annual average being 14.4°C (57.9°F). However, temperatures above 100°F or below 0°F occurred in less than half of the 20 years of record. Average temperatures increase steadily from the coldest month (January) to the warmest month (July) and decline uniformly again to winter lows. Significant secondary maxima and minima are not evident during the spring and fall seasons; thus, the yearly temperature distribution is bimodal. Mean temperatures are very uniform across the entire width of the Valley and Ridge Province — a condition that is very unusual for such a wide range of latitude.

Hilsmeier[33] used the vertical-temperature-gradient data obtained by simultaneously measuring temperatures at ground and tower elevation to calculate the percentage frequency of inversion conditions as a function of total hours for the four seasons; Table 4.14 gives the data. Inversion conditions occur about one-third of the time throughout the year.

This type of vertical temperature distribution occurs primarily as a diurnal response to radiative and convective heat transfers at the earth's surface but may be secondarily modified by both seasonal solar-energy input and cloudiness. A typical daily cycle begins when nearly homogeneous temperatures are maintained across the entire vertical span of the atmosphere in midday because the intense directly incident radiation is convectively mixed in both horizontal and vertical directions. Ridges may be slightly warmer at this time simply because of the lapse time for heat to travel down the slopes, but the differences are slight and are rapidly damped out. Nonuniformity of heat transfer is noticed first in late afternoon and early evening when the incoming solar energy declines, thus causing the upper atmosphere to become cooler than the lower atmosphere, which still receives radiative heat from the surface. A shallow flow of cool air downslope and pooling in the hollows then produces an intense surface-layer inversion, while at higher elevations an adiabatic lapse continues to exist. This lapse gradually cools by downward eddy transfer of heat and becomes increasingly stable as the night

Table 4.12. Site description and instrumentation of the Oak Ridge weather stations[a,b]

Site	Location	Ground level (ft MSL)	Telemetered instrumentation					Temperature gradient span	Upper instrument level (ft MSL)
			Temperature	Precipitation	Wind		Dew point		
					Vane	Anemometer			
Town	36°01'N, 84°14'W on the Oak Ridge Turnpike between Tyndale and Tennyson Streets at Cheyenne Hall	905	TC	WG	16 PC	3 CC	DC	None	955
Y-12	35°59'N, 84°15'W inside the Y-12 area in Bear Creek Valley in the vicinity of Bldg. 9706-2 (known as dispensary)	945	TC	WG	16 PC	3 CC	DC	55 ft	1005
ORNL	35°56'N, 84°19'W atop a 90-ft ridge in the ORNL area, which is in Bethel Valley. This also is the ORNL water tower site	886	TC	WG	16 PC	3 CC	DC	135 ft	1026
TSF	35°54'N, 84°18'W on Copper Ridge. The instruments are on and in the vicinity of the NE tower	1073	TC		16 PC	3 CC	DC	310 ft	1387
ORGDP	35°35'N, 84°23'W at the NE corner of Bldg. K-303-7 of the main gaseous diffusion plant	780	TC	EG	16 PC	3 CC	DC	None	891

[a]Surface temperatures are read at 5 ft above ground except at 4 ft at TSF. Wind equipment is at the upper instrument level.

[b]MSL = mean sea level
TC = thermocouple, aspirated
WG = weighing rain gage
EG = electronic rain gage
16 PC = 16-point contacting vane
3 CC = 3 cup contacting anemometer
DC = Foxboro dew cell

Source: W. F. Hilsmeier, *Supplementary Meteorological Data for Oak Ridge*, ORO-199, U.S. AEC Oak Ridge Operations, Oak Ridge, Tenn., Mar. 15, 1963, p. 2.

Table 4.13. Monthly temperatures and solar radiation for the Oak Ridge area, 1951–1971

Month	Temperature (°F)			Solar radiation (kcal cm^{-2} mo^{-1})
	Maximum	Minimum	Average	
January	47.0	28.8	37.9	5.6
February	51.2	30.6	40.9	6.7
March	58.7	36.3	47.5	10.1
April	71.1	46.9	59.0	12.3
May	79.1	54.5	66.8	15.3
June	85.2	62.7	74.0	15.1
July	87.3	66.4	76.9	13.4
August	86.7	65.2	76.0	13.5
September	81.5	58.7	70.1	11.3
October	71.3	47.2	59.3	9.6
November	57.8	35.9	46.9	5.8
December	48.8	30.6	39.7	4.7
Annual			57.9	123.4

Source: U.S. Atomic Energy Commission, *HTGR Fuel Refabrication Plant at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, Draft Environmental Statement*, WASH-1533, January 1974, p. 111.

Table 4.14. Calculated incidence of inversion conditions by season for the Oak Ridge area

Season	Inversion frequency (% of total hours)
Winter	31.8
Spring	35.1
Summer	35.1
Autumn	42.5
Annual	35.9

Source: W. F. Hilsmeier, *Supplementary Meteorological Data for Oak Ridge*, ORO-199, U.S. AEC Oak Ridge Operations, Oak Ridge, Tenn., Mar. 15, 1963, p. 5.

progresses. Inversion strength, that is, temperature gradient, is greater over industrialized areas than over rural areas because the artificially sustained heat production of the former at the surface after sunset magnifies the difference between the heated inversion and the cooling lapse-air layers. Earthbound diffusion of cool air during the night and the additional input of cool mountain air gradually diminish inversion intensity. Surface temperatures also decrease during this interval; therefore, by dawn, isothermal surfaces are generally horizontal. Accumulations of fog and smoke at daybreak reduce the inversion air layer to a shallow lapse region near the surface. Within two hours of daybreak and the new solar input, the inversion is dispersed at the lowest altitudes. The remainder of the atmosphere is gradually heated throughout the morning.

4.5.2.3 Precipitation

Monthly precipitation levels averaged from data collected from 1951 to 1971 are given in Table 4.15. Significant differences exist among the amounts of rainfall deposited at the

Table 4.15. Average monthly precipitation levels for the Oak Ridge area, 1951–1971

Month	Precipitation (in.)		
	Rainfall	Snowfall	Total
January	5.3	3.4	8.7
February	5.3	2.6	7.9
March	5.6	1.3	6.9
April	4.4	0.01	4.4
May	3.6	0	3.6
June	4.0	0	4.0
July	5.6	0	5.6
August	3.8	0	3.8
September	3.3	0	3.3
October	2.7	0	2.7
November	4.2	0.5	4.7
December	5.7	2.3	8.0
Annual	53.5	10.3	63.8

Source: U.S. Atomic Energy Commission, *HTGR Fuel Refabrication Plant at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, Draft Environmental Statement*, WASH-1533, January 1974, p. 111.

various weather stations. For example, mean annual precipitation from 1951 to 1962 was 139 cm (54.71 in.) in the city of Oak Ridge but only 131 cm (51.52 in.) at ORNL. Oak Ridge had measurable (greater than 0.01 in.) precipitation seven more times annually than did the ORNL station. Such differences are attributed primarily to the fact that most storm-frontal movement in this region originates in the Cumberland Mountains and then travels along a northwest-to-southeast track. Consequently, mean annual precipitation in the Valley and Ridge Region varies from greater than 147 cm (58 in.) in the northwest to less than 117 cm (46 in.) in the southeast.

The general pattern of monthly rainfall is similar at all the weather stations. Although precipitation is fairly evenly distributed throughout the year, well-defined seasonal and areal variations do exist. The greatest quantity of precipitation usually falls in January, but December, February, and March also receive heavy water input. A second maxima is recorded in July between the low-rainfall periods common to spring and autumn. Such general trends are not absolute — monthly precipitation levels may vary grossly from year to year. For example, during the 1948-1964 period, January precipitation varied from 1.86 to 10.47 in.

Clear conditions prevail 30% of the time throughout the year; partly cloudy, 25%; and cloudy, 45%. An average of 53 thunderstorms and 40 days of heavy natural fog [upper visibility limit, 0.4 km (0.25 mile)] occur in a year. Generally, snowfall does not have an appreciable climatological significance in the Oak Ridge area. However, in unusual years, it may represent a major portion of the winter precipitation: For example, in 1959-1960, 105 cm (41.4 in.) fell.

Flood risk on the Clinch River and the East Fork of Poplar Creek has been evaluated by TVA.[35,36] Regional floods predominantly occur in the December-to-April period of frequent and intense cyclonic storms. Besides being the season of maximum precipitation, winter is also the time of greatest surface runoff, since much of the vegetation is dormant. The heavy precipitation deposited in summer months is generally not as critical because very little of this hydrological input is diverted to surface-water flow. However, damaging flash floods can result from intense thunderstorm activity during the summer season, especially on unregulated tributaries.

The gravity of the flood risk on the Clinch River was diminished considerably by the closure of the TVA dams at Norris, Melton Hill, and Watts Bar. From 1883 until the closure of Norris Dam in 1936, 47 floods overflowed the Clinch River floodplain. Since the completion of this dam, only once out of 23 times has a flood surpassed the storage capacity of the reservoir (this in 1937). This particular flood affected the entire Mississippi Valley, and releases of 1.3 ft greater than the present flood stage on the Clinch were permitted in order to provide critically needed storage space during the continuing rains. Construction of the Melton Hill Dam submerged much of the former floodplain and reset the flood-stage level on the Clinch at 795 ft. However, above this level, Melton Hill Dam serves no flood-control function. With the regulation of headwater flows at Norris, the backwater regulation of Watts Bar has become the dominant factor that determines the water levels along the lower Clinch. The combined effects of these three dams should prevent almost all future excessive flows on the Clinch River.

On the tributaries of the Clinch below Norris, extreme floods may result from two types of storms: (1) intense rainfall of reasonably long duration during winter, when infiltration and other losses are generally small and (2) intense cloudbursts of short duration during summer or early fall, when land- and plant-loss rates are high. Because of the large storage capacity of the TVA reservoirs, storms of the second type that occur below Norris Dam pose a greater flood risk to the Oak Ridge Reservation than does a regional sustained rainfall that covers the entire Clinch River Valley. High-intensity summer precipitation occurs frequently on the eastern continental range when warm moist air flows north from the Gulf of Mexico. The most intense rainstorm of this type during the period of record in the city of Oak Ridge was that of August 10, 1960, when 18.9 cm (7.43 in.) of rain fell in 3.3 hr. At the storm center, 0.75 mile north of the weather-station gauges, about 22.9 cm (9 in.) of precipitation fell. Such cloudbursts usually have a very restricted areal extent. For example, in that storm, only 0.08 cm (0.03 in.) of precipitation was recorded at the ORGDP station 19 km (12 miles) away. Rainfall of this nature is a source of considerable concern since it cannot be controlled by operation of the TVA dams.

4.5.2.4 Wind

Wind roses generated from measurements made during both lapse and inversion conditions in all seasons for the ORGDP area are given in Fig. 4.8. More specific atmospheric dispersion characteristics can be deduced from data on the joint frequency distribution of wind direction, wind velocity, and atmospheric stability (according to Pasquill's seven classes). These data are summarized in Table 4.16.

These data indicate a pronounced bimodal wind-direction pattern which consists of prevailing up-valley (southwest and west-southwest) and down-valley (northeast and east-northeast) flow. This type of wind regime reflects the topographic orientation of the Valley and Ridge Province. The stability characteristics of these two directional channels are also nearly identical and represent the critical dispersion conditions. However, the similar up- and down-valley flows are probably caused by two different meteorological circumstances. The down-valley draft, identified with drainage or gravitational flow down local slopes and the broader Tennessee Valley, prevails during the inversion conditions of late evening through midmorning, whereas regional or synoptic pressure patterns dependent on solar inputs are very weak. However, in the daytime lapses, up-valley flow results when the regional or synoptic flows aloft become sufficiently strong to dominate the opposing local, down-valley, gravitational winds. Since these higher regional winds do not exert as pronounced an influence on valleys, the local valley wind regime may even maintain its structure and flow in a direction opposite to that of the regional wind tracts.

The opposing forces of regional and local winds counteract one another to yield a rather high occurrence of calm periods (23%) and the lowest wind-velocity classes (1 to 3 mph, 28%; 4 to 7 mph, 26%). In fact, the average wind speed for the Oak Ridge area is only 4.4 mph. Severe windstorms are notably rare. A major factor in the stability of air movement is the Cumberland Plateau, which diminishes the force of winter and early-spring storms. As is the case in rainstorms, local irregular ridges further minimize wind impact. The peak gust of record on the reservation is 95 km/hr (59 mph), and the probable occurrence rate of gusts of tornadic proportion is only once in every 91,000 years.[37] Tornadoes in the southeastern states in the past half century have been of small scale and short path length and have caused only minor damage.

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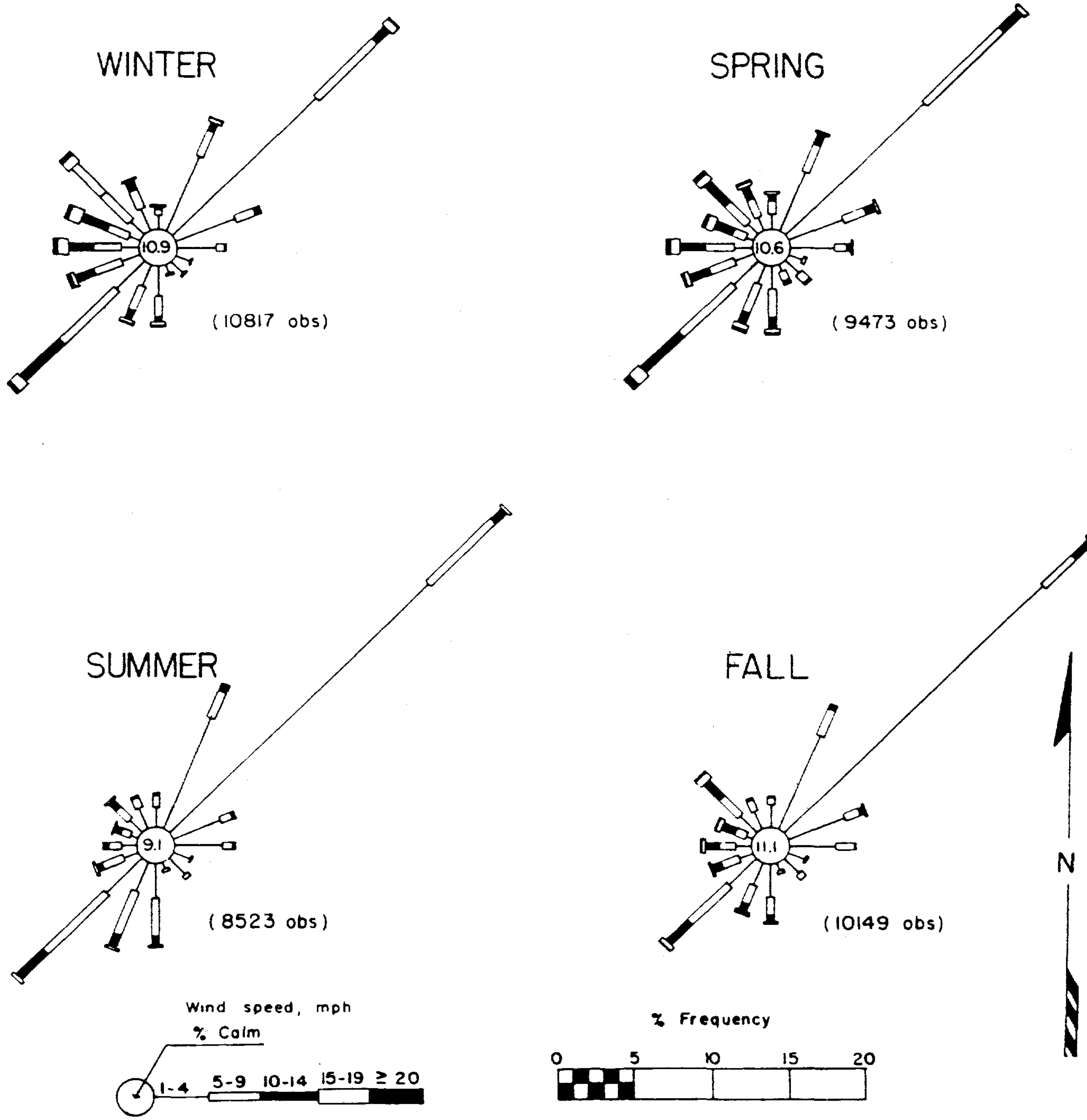

Fig. 4.8. Wind roses for the ORGDP weather station, lapse and inversion conditions, combined by season, 1956-1960. Source: W. F. Hilsmeier, *Supplementary Meteorological Data for Oak Ridge*, ORO-199, U.S. AEC Oak Ridge Operations, Oak Ridge, Tenn., Mar. 15, 1963, p. 41.

Table 4.16. Frequencies of wind directions and true-average wind speeds

Wind direction	Frequency	Wind speeds for each stability class (m/sec)						
		A	B	C	D	E	F	G
N	0.029	2.59	2.88	1.64	2.06	1.35	1.24	0.99
NNW	0.020	2.93	2.77	2.13	2.23	2.09	0.67	1.32
NW	0.029	3.22	2.37	1.80	2.12	1.58	0.98	0.97
WNW	0.045	3.06	2.04	1.14	1.51	1.14	0.87	0.86
W	0.061	3.39	2.46	2.15	1.69	1.30	0.96	0.93
WSW	0.115	3.49	2.82	2.31	2.26	1.71	1.35	1.35
SW	0.053	3.76	2.75	2.72	2.38	1.59	1.36	1.22
SSW	0.032	3.45	4.26	2.32	2.34	1.37	1.03	1.45
S	0.019	4.59	2.71	3.50	1.91	1.63	1.15	0.55
SSE	0.060	3.38	3.24	3.93	2.73	1.55	1.06	0.89
SE	0.068	4.67	4.02	3.82	3.57	2.94	1.22	1.19
ESE	0.064	4.32	3.75	4.60	3.69	2.78	1.27	1.33
E	0.040	4.39	3.56	2.34	3.39	2.50	1.23	1.25
ENE	0.101	3.60	3.83	3.30	4.07	2.67	1.61	1.72
NE	0.181	5.27	4.51	4.66	4.63	2.94	1.66	1.79
NNE	0.076	4.48	3.76	3.27	3.78	2.17	1.29	1.55

4.5.2.5 Air quality

Average meteorological conditions. The latest national[38] and Tennessee state[39] air quality standards (Table 4.17) differ little from those promulgated in 1971.[40] Among those pollutants listed, annual total suspended particulate maxima and 24-hr sulfur dioxide (SO_2) maxima have been measured in Roane and Anderson counties.[41] Values for particulates in Roane County varied from 75.5 to 100 $\mu g/m^3$ (exceeds national standard of 75 $\mu g/m^3$) and, for SO_2, from 365 to 800 $\mu g/m^3$ (exceeds national standard of 365 $\mu g/m^3$). Values for particulates in Anderson County were between 37.5 and <75.5 $\mu g/m^3$ and, for SO_2, <180 $\mu g/m^3$ (both values are below national standards).

Stable, short-term meteorological conditions. Severe conditions limit the dispersion of gases (i.e., cause an increase in air concentrations); such conditions may be related to any one or a combination of the following: atmospheric calms, moderate to extreme atmospheric stability (Pasquill types F and G stability), and upper-level inversions. The frequency of atmospheric calms is low (about 5%). Pasquill type F stability occurs about 40% of the time in the east Tennessee region.[42] In 1974, Pasquill type F stability occurred locally about 14% of the time.[43] However, these low-level inversions (Pasquill types F and G) occur mainly at night.

4.6 ECOLOGY

4.6.1 Terrestrial ecology

4.6.1.1 Vegetation

Appalachian oak forest is the potential natural vegetation of much of the ORGDP region.[44] Northern hardwoods are climax types found in coves that are interspersed along the dissected ridge system. Currently, most of the region is covered by a second-growth forest composed of seral plant communities (Fig. 4.9). Particular seral communities found within a 3000-m radius of the site are:

Table 4.17. Primary ambient air quality standards for the United States and the state of Tennessee

Pollutant	Interval	Concentration ($\mu g/m^3$)	
		National[a]	State[b]
Particulates	24 hr	260	260
	Annual	75	75
Sulfur oxides	24 hr	365	365
	Annual	80	80
Nitrogen dioxide	Annual	100	100
Carbon monoxide	1 hr	40,000	40,000
	8 hr	10,000	10,000
Photochemical oxidants	1 hr	160	160
Hydrocarbons	3 hr	160	160
Fluorides[c]	12 hr	3.7	3.7
	24 hr	2.9	2.9
	7 days	1.7	1.6
	30 days	0.84	1.2
	Annual	0.50	

[a]Environmental Protection Agency, *Air Quality Data — 1977 First Quarter Statistics*, EPA-450/2-78-010, Research Triangle Park, N.C., 1978.

[b]Tennessee Air Pollution Control Regulations, Department of Public Health, Division of Air Pollution, Nashville, Tenn., December 1972.

[c]No national standards are established for fluorides; those listed are the most restrictive state standards (WAC-18-48-130, ambient air standards, State of Washington, Dept. of Ecology, Ch. 18-48 WAC, fluoride standards, effective Feb. 4, 1971).

Community type	Acres	Percentage
Bottomland hardwoods	93	<1
Oak-hickory	1270	18
Mixed-mesophytic forest	10	<1
Pine and pine hardwoods	2516	36
Cedar, cedar-pine, cedar-hardwoods	140	2
Unforested	2215	32
Open water	466	7
Buildings and highways	293	4
Total	7003	100

The original mature forests were extensively cleared and the land cultivated during settlement. Since cultivation ceased in 1942, cultivated fields have developed into forests through natural succession. Between 1948 and 1954, many of the abandoned fields were planted with various pine species.[1] These plantations have been maintained with little or no invasion by deciduous hardwoods. Other abandoned fields not replanted with pines underwent a natural succession from Virginia pine and eastern red cedar to hardwood pine—cedar forests. This is an intermediate or developmental association, and some pine remains even when hardwoods become dominant. More specific descriptions of these plant communities follow.

Bottomland hardwood forests

Bottomland hardwoods are rich mesophytic forests dominated by yellow poplar. Common associates are various oaks, shortleaf pine, sweet gum, sycamore, black walnut, and hickories. Understory trees include redbud, flowering dogwood, black gum, sourwood, red maple, and white ash. Although

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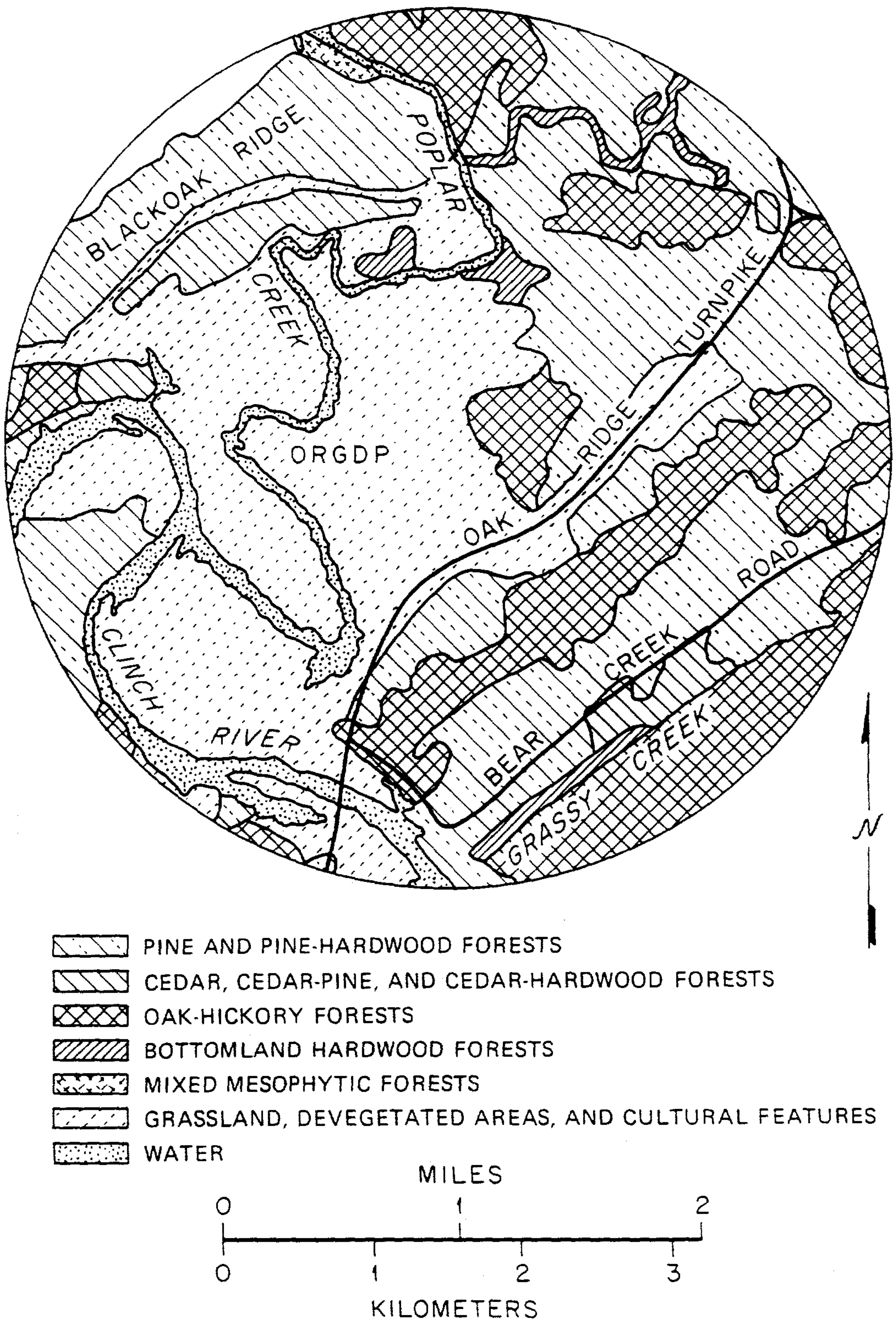

Fig. 4.9. General vegetation cover in the ORGDP area.

many herbaceous species are present, Christmas fern and hydrangea account for nearly 90% of the understory biomass. The species composition of the yellow poplar forest (bottomland hardwoods) of the Oak Ridge Reservation has been characterized by Sollins.[45]

Oak-hickory forests

Oak-hickory forests occur along ridge tops and on lower slopes. The overstory of this forest consists mainly of oaks and hickories. Common subcanopy associates are red maple, black gum, and sourwood. The composition of the oak-hickory forest is more varied than that of the bottomland forest. Ground cover vegetation consists principally of assorted grasses, greenbrier, Virginia creeper, poison ivy, bracken fern, and many species of tree seedlings.

A zeric variant of the oak-hickory forest is the chestnut-oak forests which occur on relatively dry ridge tops that have a thin mantle of soil. Characteristic species are black oak, chestnut oak, scarlet oak, and southern red oak. Decaying stumps of American chestnut can be found within these areas. On dry ridge tops, chestnut oak has replaced the American chestnut, a species that was nearly eliminated by chestnut blight. A detailed species list for this forest type is given in Tables 2.7-2 through 2.7-4 of ref. 1.

Mixed mesophytic forests

These northern hardwoods (cove hardwoods) are found interspersed along the dissected ridge system. This association is the most varied and luxuriant in the eastern deciduous forest. The overstory of this forest consists mainly of sugar maple, beech, yellow poplar, magnolia, basswood, white pine, and hemlock. The understory is very dense with thickets of mapleleaf viburnum, pawpaw, and rhododendron. Herbaceous species include maidenhair fern, walking fern, Christmas fern, hepatica, saxifrage, jack-in-the-pulpit, anemone, and blue cohosh. Parasitic beech drops commonly occur under beech trees. Detailed structural data and the composition of northern hardwood stands found adjacent to the site are given in Tables 2.7-27 and 2.7-28 of ref. 1.

Pine and pine-hardwoods

Two major forest communities have been defined within the natural pine areas: native pine forest and loblolly pine-hardwood forest. Native pine forests are dominated by shortleaf pine and Virginia pine. The diameter at breast height of these trees varies from 6 to 13 in. Woody subordinate species include white ash, southern red oak, yellow oak, hickory, red maple, flowering dogwood, black cherry, and Carolina buckthorn. Ground cover forms a dense mat, and the most abundant species are Japanese honeysuckle, poison ivy, and greenbrier. Light intensity in these stands is relatively high compared with that in the pine plantations, because of a more open canopy. Consequently, an extensive selection of herbaceous species is found here, including ebony spleenwort, Canada cinquefoil, spotted wintergreen, bedstraw, bush clover, rattlesnake plantain, small ragwort, and wild lettuce. Detailed structural data and the composition of natural pine stands found adjacent to the site are given in Tables 2.7-29 through 2.7-31 of ref. 1.

Loblolly pine-hardwood is a transitional forest type that is undergoing succession toward a hardwood climax. This forest type occurs on drier sites. Associated species are southern red oak, white oak, post oak, northern red oak, hickories, shortleaf pine, persimmon, and scarlet oak.

The majority of the pine plantations consist of loblolly pine with scattered areas of shortleaf pine. Most of the plantations are on old-field sites in the valleys and on lower slopes.[46] The trees, generally row-planted on a nominal 6- by 6-ft spacing, have developed a tightly closed canopy. Hardwood subcanopy species are dogwood, red maple, sassafras, and yellow poplar. Ground-cover herbaceous species are restricted due to insufficient light and a dense pine litter layer. Thus, ground cover is predominantly twining vines, such as Japanese honeysuckle, poison ivy, Virginia creeper, and blackberry. Detailed structural data and the species composition of pine plantations found adjacent to the site are found in Tables 2.7-33 through 2.7-38 of ref. 1.

Cedar, cedar-pine, and cedar-hardwoods

Cedar is a pioneer tree species which invades fields soon after their abandonment. Three distinct cedar communities occur on the reservation: cedar glades, pine-cedar, and hardwoods and cedar.

Cedar glades are edaphic climax communities (restricted by soil conditions). Tree density is low and there is nearly continuous ground cover of grasses and forbs. The dominant overstory tree species is eastern red cedar, which ranges in height from 15 to 25 ft and has stem diameters of 3 to 8 in. Few woody species other than eastern red cedar occur; however, herbaceous species are plentiful. These stands are characterized by the bare calcareous soils and rock outcrops. Table 2.7-39 of ref. 1 lists the species composition of a cedar glade just south of the site. The cedar glades of the reservation are discussed in more detail elsewhere.[47]

Natural pine-cedar communities are dominated by eastern red cedar and Virginia pine. The associates are numerous, but none is particularly characteristic.[48] They include post oak, chestnut oak, red oak, red maple, and dogwood. The community occurs on dry to moist sites and is probably replaced by pine-hardwoods.

Mixed hardwood-cedar communities are relatively young successional hardwood forests. Dense vegetation forms extensive thickets of saplings and sparse ground cover. However, many weedy herbaceous species are interspersed throughout this cover type.[49]

Unforested areas

Unforested areas within 300 m of the ORGDP site include transmission line rights-of-way, maintained lawns around the gaseous diffusion plant, and abandoned fields. The early stages of plant succession on abandoned land on the Oak Ridge Reservation and throughout the Southeast are dominated by annual and perennial forbs and grasses. If succession is allowed to continue (i.e., the area is not mowed or bush-hogged), this community is usually followed by a shrub phase when tree seedlings, rapidly growing shrubs, and woody vines invade. Many transmission line corridors and land recently cleared of timber contain this shrub community. Important species include winged sumac, honeysuckle, smooth sumac, persimmon, and various tree saplings. Grasses, lespedeza, greenbrier, and brambles are important ground-cover species. Trees eventually overtop and shade out the shrubs and herbs until forest cover is reestablished.

Unique vegetation areas

Unique vegetation areas within 10 miles of the site include The University of Tennessee Arboretum near Oak Ridge, a nearly pure stand of sassafras near the Dosimetry Application Research Facility Reactor at ORNL, and a stand of eastern red cedar near The University of Tennessee Agricultural Farm.

At Jones Island, on the Clinch River about 3 miles upstream from the site, 40 acres are being used for research on plant genetics and physiology.

Based on the definition of a natural area as any climax community that is ecologically unusual in terms of extent or occurrence, there are three natural areas within a 3000-m radius of the ORGDP.[1] The area east of the junction of State Highways 95 and 62 contains old-growth pine and hardwood species in a relatively undisturbed setting.[45] The other two areas are located on Grassy Creek. These are old-growth beech-maple and beech–mixed oak areas that represent climax communities of particularly good quality. These areas have reached self-perpetuation and are in equilibrium with the environment. The stands occur in a narrow stream bottom which contains many uncommon spring ephemeral plant species, including the threatened black snakeroot, which require cool, humid growing conditions.

Ecological research areas that are within a 3000-m radius include four animal study areas, three transmission-line management areas, a cooling-tower-drift study area, and a wildlife refuge.[46]

4.6.1.2 Wildlife

Vegetative communities in the site area, primarily woodland, provide varied habitat for many wildlife species. Many communities found on the site are typical of east Tennessee, an area rich in flora and fauna. Game and economically important mammals, birds, and herpetofauna (reptiles and amphibians) will be considered in the following sections.

Mammals

The greatest diversity of mammals occurs in the mixed hardwoods and hardwood-cedar-pine association, whereas the least diversity occurs in pine plantations and lawns near the gaseous diffusion plant. ORNL studies of the Oak Ridge area, and particularly of the Melton Valley area, can be used to characterize the mammalian fauna.[1,50] Economically important mammals on the Oak Ridge Reservation are described in the following.

White-tailed deer (*Odocoileus virginianus*) is the only big game species that is common on the reservation. This animal is the most important big game mammal of the eastern United States, but hunting is not permitted on the reservation. Deer occur throughout the area and prefer the hardwood-pine forests and ecotones, such as the overgrown, abandoned transmission corridors that provide preferred browse. Within its home range, usually 1 to 2 miles, the deer feeds mainly on twigs, leaves, and fruits of oaks.[51]

Cottontail rabbits (*Sylvilagus floridanus*) occur throughout the site but primarily near old fields, open areas (transmission corridors), and forest edges. They are strict vegetarians and eat mainly green grasses and herbs.[52] When these foods are not available within the cottontail's 3- to 20-acre home range, bark and twigs of woody plants are consumed. They are also important due to their status in food chains as a prey species for several carnivorous mammals and birds.

The eastern gray squirrel (*Sciurus carolinensis*), a common animal, primarily inhabits mature deciduous woods but frequently uses pine woods and sometimes visits hedgerows and lone nut-bearing trees in fields. Within its home range (generally 2 to 7 acres), acorns account for 25% to 50% of this squirrel's diet; hickory and beech nuts are also eaten.

Opossums (*Didelphis marsupialis*) can be found mainly in moist, wooded areas; they are omnivores — insects, small mammals and birds, and fruit make up their diet. They are solitary by nature and strictly nocturnal, with a home range of 15 to 40 acres. Road kills of this species are frequent.

Woodchucks (also called groundhogs) (*Marmota monax*) are common on the reservation. They live in or near lush herbaceous vegetation; the burrows are often near a road shoulder or other opening. Woodchucks are often sighted on the lawns of the ORGDP, where they use drainage tiles as burrows. The woodchuck's principal foods are grasses and clover, and its home range is 40 to 160 acres.

Beavers (*Castor canadensis*) prefer waterways with trees on the bank, and some beaver populations occur in the Clinch River below Melton Hill Dam. They feed primarily on the bark and outer woody layers of alders, birches, poplars, willows, maple, cottonwood, and other trees; numerous aquatic plants are also eaten.

Muskrats (*Ondatra zibethica*) occur along the Clinch River, area streams, and other places having a dependable water supply. Locally, this species lives in burrows. They are essentially vegetarians, but occasionally will eat animal food such as fish, mussels, insects, crayfish, and snails.

Raccoons (*Procyon lotor*) are common on the reservation and prefer wooded areas near streams or other water bodies. This primarily nocturnal animal feeds on fruits, seeds, bird eggs, crayfish, and other small invertebrates. Its home range is typically 1 to 2 miles up or down wooded stream banks. Road kills of this species are not uncommon.

Striped skunks (*Mephitis mephitis*) are found in almost all the habitats of the area. The animal becomes active at dusk or nighttime and forages for small rodents, cold-blooded vertebrates, insects (especially white grubs), eggs, berries and other vegetative material, and, occasionally, carrion. The striped skunk is another species frequently killed on roads of the area.

Red foxes (*Vulpes fulva*) are fairly common on the reservation. In 1958, 300 red and gray foxes were killed for rabies control. The red fox, which is about twice as common as the gray fox,[50] prefers broken, sparsely settled country, but is cosmopolitan in its habitat distribution. Within its home range of 1 to 2 sq miles, the red fox's diet staples are small mammals such as mice and other rodents and rabbits. It will also eat insects and birds, and, in the summer and fall, fleshy fruits and seeds provide about one-fourth of its diet.[51]

Gray foxes (*Urocyon cinereoargenteus*) prefer a mixed hardwood forest habitat, although they are not strictly limited to that community. The gray fox, more omnivorous than the red fox, fairly consistently eats acorns and persimmons. The animal portion of the diet is similar to that of the red fox. The gray fox is more adapted to a forest existence than is the red fox.

Longtail weasels (*Mustela frenata*) are found in almost all habitats near reliable sources of water. However, they prefer bushy field borders, brushlands, open woodlands, woodlands bordering cultivated fields, and pastures. They are quite adaptable and willing to live in close proximity to man as long as suitable prey is available. The longtail weasel is strictly carnivorous and eats primarily meadow mice, cottontail rabbits, and white-footed mice. The home range is normally 30 to 40 acres, with populations of 15 to 20 per square mile considered to be quite high.[52]

Mink (*Mustela vison*) is an uncommon resident of the reservation and is found mainly along forested log-strewn and/or bushy streams. Minks range over a wide area to procure their food, which consists of reptiles, amphibians, small mammals, and birds.

Bobcats (*Lynx rufus*) are rare. They are known from a few sight records and from trapping studies on the reservation. The killing of a female bobcat in 1953 by steel riggers at the ORGDP site has also been documented.[50] There is little knowledge on population numbers in this area for this secretive species.

Birds

There are several detailed studies of the area bird fauna.[53-55] Economically important birds in the area are described below.

Bobwhite quail (*Colinus virginianus*) is the most abundant upland game species throughout the site. It prefers brush fields, abandoned farms, and open pine woods. Bobwhites eat a varied diet of leaves, buds, fruits, seeds, insects, and snails. Due to intensive reforestation of the reservation, the bobwhite is probably disappearing from the area.[50]

Ruffed grouse (*Bonasa umbellus*), a woodland game bird, occurs throughout the deciduous forest. Grouse prefer hardwood and brushy cover, using conifers in winter and abandoned fields and orchards through the remainder of the year. The adult diet, which is almost exclusively vegetarian, consists of fruits, leaves, and buds.

Mourning doves (*Zenaidura macroura*) are also abundant upland game birds and are rather generally distributed throughout Melton Valley. This species uses open areas for feeding, and gravel roads are frequented as a source of grit. Some may feed as much as a mile or more from their nests. Mourning doves occupy overgrown fields and openings in the woods but are not found in extensive areas of uninterrupted woods.

Canada geese (*Branta canadensis*) are the most important of the nesting waterfowl on the Oak Ridge Reservation. Breeding pairs were introduced to the Melton Valley, including the wildlife refuge at the site, by the Tennessee Fish and Game Department, and they are successfully nesting. The wood duck and hooded merganser also breed on the reservation. Wintering flocks include the mallard, black, pintail, gadwall, ring-neck, golden-eye, bufflehead, and common merganser. The Clinch River also provides a sanctuary for migratory flocks of ducks and Canada geese. The American widgeon, blue-winged and green-winged teal, redhead, canvasback, lesser scaup, ruddy duck, red-breasted merganser, and American coot are particularly common during migration.

Herpetofauna

Herpetofauna of the Oak Ridge area were described by Johnson.[56] The bullfrog (*Rana catesbeiana*) is found in ponds, reservoirs, marshes, and other quiet permanent water that provides both depths and shallows and abundant cover. Its food consists of aquatic invertebrates and crustaceans and many terrestrial insects.

The snapping turtle (*Chelydra serpentina*) resides mainly in streams, marshes, and ponds on the reservation. It can be found in any aquatic situation but prefers mud bottoms. Its food consists of aquatic plants, crayfish, fish, clams, amphibians, and carrion.

The eastern spiny softshell (*Trionyx spinifer spinfer*) is essentially a river turtle, to be found in the Clinch River.[56] Its diet is similar to that of the snapping turtle.

In the site area, stream and creek banks are habitat for the greatest variety and density of frogs, whereas moist ravines are most preferred by salamanders.[1] Fence lizards can be found on roadsides and in old fields.[1] Important game species include the bullfrog, common snapping turtle, and eastern spiny softshell turtle.

4.6.2 Aquatic ecology

This section contains a description of the five major biotic communities in the waters adjacent to ORGDP — phytoplankton, periphyton, zooplankton, benthic macroinvertebrates, and fish. The information has been obtained primarily from the biological monitoring effort (see Appendix B) conducted for the ORGDP site during 1977 and 1978. Details of the methods used in that study are contained in ref. 15. The sampling stations employed are shown in Fig. 4.10. Studies conducted for proposed projects nearby have also been consulted (primarily refs. 2 and 57). This discussion represents a summarization of the salient features of the available studies; considerable additional information is available in the cited reports.

4.6.2.1 Phytoplankton

The phytoplankton communities of the waters around ORGDP are typical of riverine-reservoir habitats of the southeastern United States. During most of the year, diatoms are the predominant group, with peaks occurring occasionally among the green and blue-green components. Densities are greatest in late spring and early fall and are generally greater in the Clinch River stations farthest downstream (probably due to the greater pooling effect of Watts Bar Reservoir in these areas). The upper reaches of Poplar Creek display lower densities from the influence of swifter currents and a greater canopy coverage, and the community composition differs from the other stations.

In addition to the ORGDP monitoring effort, there have been three major studies conducted on the phytoplankton communities of the area. These are discussed in ref. 15. The discussion here will largely center on the data obtained from the recent monitoring program. The results of all studies are similar, after allowances are made for differences in methodology.

The maximum densities in 1977-1978 occurred around the ORGDP site at PCM 0.5 (8480 units/ml) and CRM 11.5 (just below the mouth of Poplar Creek, 12,890 units/ml). These were reported in late spring, 1978, and were largely the result of a bloom of *Carteria* sp. (a green alga). Also abundant were *Cyclotella* sp. (a diatom) and *Rhodomonas* sp. (a cryptomonad). During this time, a similar species composition (but of lower density — 4000 units/ml) was found at the CRM 10.5 station. The peak algal density at CRM 15.0 occurred at the same time (only 1956 units/ml); *Rhodomonas* sp. and an unidentified flagellate made up 75% of the total. The upstream station on Poplar Creek had the lowest peak density of any of the stations (528 units/ml in May), and the majority of the organisms present were benthic diatoms (thus, not true phytoplankters). The paucity of phytoplankton was probably largely due to the dense canopy and relatively swift current (compared with the other stations).

The late summer–early fall pulse at the lower Poplar Creek and Clinch River station was dominated by *Scenedesmus* spp. (which composed 44% to 77% of the total at two of the Poplar Creek sites), *Cyclotella*, and *Synedra*. Some of the stations also contained a large percentage of blue-greens (26% to 60% of the total). Common genera were *Schizothrix*, *Oscillatoria*, and *Merismopedia* (*Agmenellum*). Total phytoplankton densities were less at this time of the year than they were during the spring peak, but a maximum of 9220 units/ml was obtained at the PCM 0.5 site.

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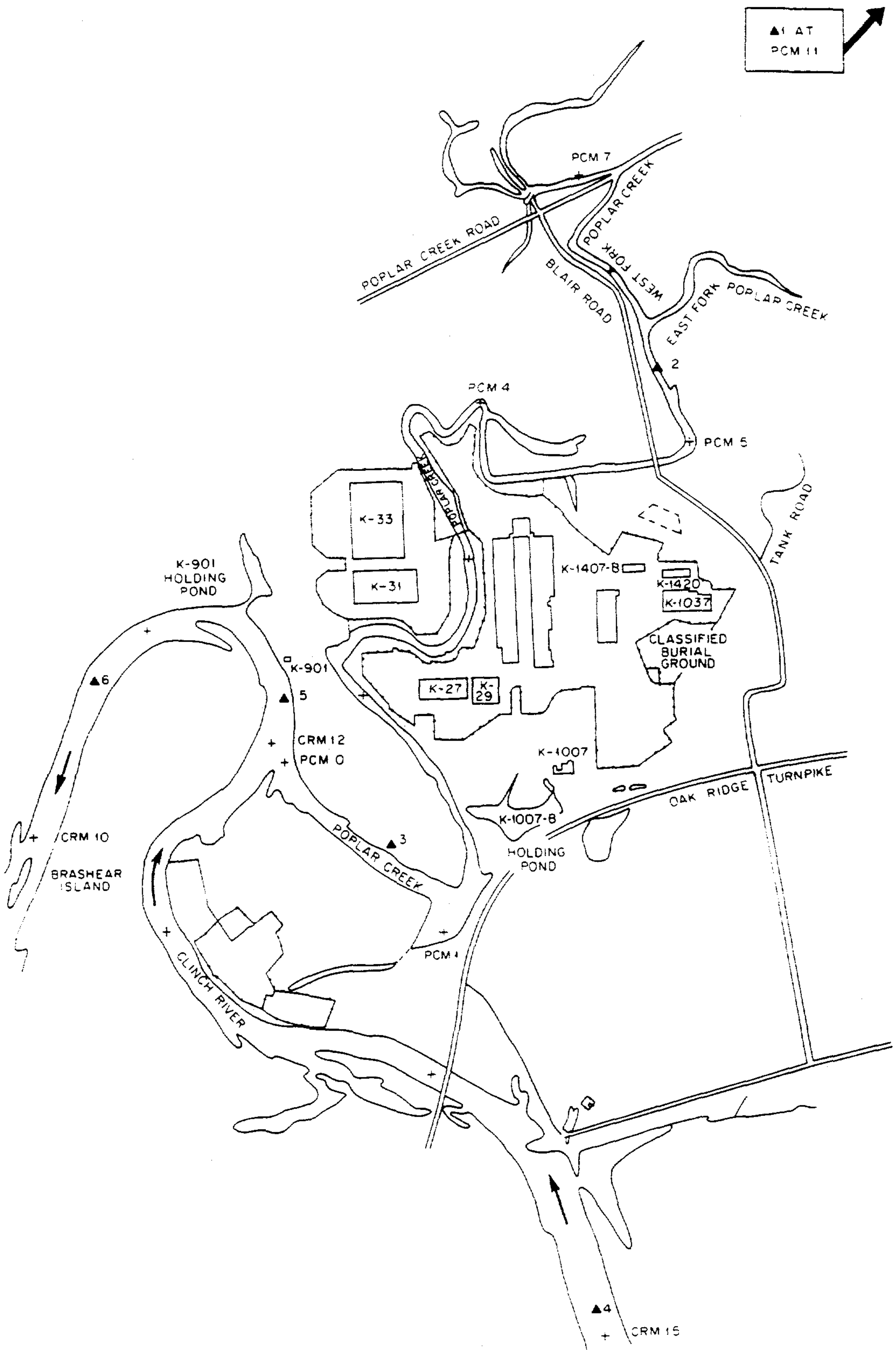

Fig. 4.10. Location of the six biological stations (▲) on Poplar Creek and the Clinch River. Sampling of the phytoplankton, periphyton, zooplankton, benthos, and fish communities was conducted from April 1977 through March 1978. Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

It is probable that various factors limit algal production in the vicinity of ORGDP. Although temperature undoubtedly influences growth in the winter, there is some evidence to suggest that, in parts of the Clinch River, it also functions as a limiting factor in the summer.[15] The release of cold hypolimnetic waters from Melton Hill Dam frequently results in temperatures in the Clinch that are appreciably lower than those in Poplar Creek (Sect. 4.4.1.1). Turbidity also likely influences algal photosynthesis, especially in Poplar Creek, by attenuating incident radiation. Nutrient levels are generally sufficient to support a large biomass (Sect. 4.4.1.1); greater maximum cell densities could be expected if the clarity and water temperature were greater. However, recorded densities indicate that, at least in some portions of both stream systems, the phytoplankton probably contribute significantly to the food base of other organisms. In the lower reaches of Poplar Creek and in much of the Clinch River, autochthonous inputs undoubtedly exceed allochthonous ones.

4.6.2.2 Periphyton

The pattern of periphyton (here defined as all attached algae) dominance and abundance from June 1977 through March 1978 was typical of that found in the Clinch River in previous years.[1,58] The relative contribution of diatoms was highest during the cooler months (November through February), when they made up 87% to 99% of the total, whereas blue-green and green algae substantially increased during the summer and early fall.[15]

Station differences were most evident in Poplar Creek, where both density and biomass were lowest at the two upstream sites; daily mean densities at PCM 11, 5.5, and 0.5 were 567, 2862, and 13,185 units/cm^2 respectively. In contrast, monthly periphyton densities in the Clinch River were often two orders of magnitude greater than values from the two upstream Poplar Creek sites. However, from November 1977 through March 1978, total densities at PCM 5.5 were similar to those in the Clinch River.[15]

Stations PCM 5.5 and 11.0, with daily average ash-free dry weight biomass values of 66 and 31 mg/m^2, respectively, showed little temporal variation. As with density, biomass at PCM 0.5 was most similar to the Clinch River station, which showed substantially greater production from August through November. Each of these stations averaged greater than 160 mg/m^2 per day during this period.[15] The resemblance of PCM 0.5 to Clinch River stations can be attributed to the influence of Watts Bar Reservoir and the decreased importance of canopy light inhibition in the downstream reaches of Poplar Creek.

Blue-green and green periphytic algae were relatively abundant during late summer and early fall, constituting a substantially greater relative fraction during this period at Poplar Creek sites (11% to 54%) than at Clinch River sites (<10%). This contrast is due to the fact that although nondiatom densities were often of the same magnitude in both streams, diatoms were much more abundant in the Clinch River.

The lowest population densities of blue-green algae occurred at the two upstream Poplar Creek stations and at CRM 15.0. In addition, unicellular green algae were a common constituent of the PCM 0.5 community during this period.[15]

Periphyton densities, composition, and seasonal variations were typical of moderately turbid rivers of the eastern United States.[59] Although a periphyton community can produce a major portion of a stream's particulate organic carbon,[60] it is doubtful that this is the case for the habitats considered here. Comparatively, the Clinch River and lower Poplar Creek are more autotrophic than the upper reaches of Poplar Creek because litter fall and runoff contribute substantial amounts of detritus there.

4.6.2.3 Zooplankton

The Rotifera was the most common group of zooplankton collected (by Clarke-Bumpus surface tows) from April 1977 through March 1978. This group consistently accounted for over 85% of the total zooplankton numbers from May through October at all Clinch River stations, a dominance characteristically found in riverine systems.[59] This pattern was also characteristic of previous Clinch River zooplankton studies, in which rotifers commonly accounted for more than 90% of all organisms during the warmer months.[1,57,58] However, rotifers typically accounted for less than 50% of the total during the low standing crops of the winter season. The other major groups of zooplankton, the Copepoda and Cladocera (Crustacea), were periodically abundant during the summer and fall.

In contrast to Clinch River zooplankton, upstream Poplar Creek communities were dominated to a lesser extent by rotifers. The average annual relative abundance of the group was 48% at PCM 11.0 and PCM 5.5 and 55% at PCM 0.5. The latter site's proportion was somewhat similar to that of the Clinch River, where rotifer abundance ranged from 62% (CRM 11.5) to 71% (CRM 15.0). The community at PCM 0.5, near the mouth of the stream, exhibited seasonal shifts intermediate between those of upstream stations and those of the Clinch River.[15] The occurrence and composition of the community at maximum standing crop values at PCM 0.5 and at CRM 11.5 (just below the mouth of Poplar Creek) were similar and were readily distinguishable on this basis from the CRM 15.0 community.

Average annual densities at all three Poplar Creek sites were significantly lower than the Clinch River densities, which did not differ significantly from each other. Densities at the upper Poplar Creek site (PCM 11.0) were typically very low (less than 1.0 organism per liter). Significant zooplankton community development at this station is precluded by the relatively swift current, absence of productive backwater areas, and low primary production.[15]

Two rather well-defined density peaks were evident in the ORGDP survey — one in early summer (June and July) and one in the fall (September to November). An exception was PCM 5.5, which exhibited a slightly later second peak. Maximum Clinch River densities were 105.0 organisms per liter (at CRM 11.5) and 104.5 organisms per liter (at CRM 10.5); the maximum in Poplar Creek was 92.5 organisms per liter (at PCM 0.5). Fall peaks were lower than those in the summer at all stations except CRM 10.5. Zooplankton densities recorded in previous studies were often much higher than those of the ORGDP survey.[1,57,58] Many of these differences may be related to natural variability in populations from year to year, differences in sampling methodologies, and sporadic reservoir releases from Melton Hill Dam.

Population fluctuations throughout the year were due largely to changes in the numbers of the rotifer genera *Brachionus, Keratella,* and *Polyarthra,* described by Williams[61] as the most abundant genera found in U.S. waterways, and also *Asplanchna* and *Synchaeta,* which were largely responsible for zooplankton population increases from August to early October at Clinch River sites. Much of the seasonal succession of zooplankton and the occurrence of maxima were temporally similar to that of phytoplankton in the area. Thus, summer rotifer abundance may have been partly related to the size of nannoplanktonic cryptophyte algal populations in the study area, a probable food source. Likewise, coincident peaks of the rotifer *Conochilus* and cryptophytes occurred at PCM 5.5 in mid-July.

Cladoceran densities tended to exceed copepod densities during the population peaks at the two lower Poplar Creek and two lower Clinch River sites and during December and January at all Clinch River stations, although the actual numbers were minimal at this time. Spring copepod numbers were similar at Clinch River sites and exceeded cladoceran densities during the months of April and May 1977 and March 1978.[15]

Dominant cladocerans identified in the ORGDP study included *Bosmina longirostris* and *Leptodora kindtii. Leptodora,* an important predator, displayed a summer maximum coincident with low densities of *Bosmina.*[15] *Sida crystallina* was also an abundant constituent of the community in the ORGDP survey, but was not commonly recorded previously. In contrast, the cladoceran *Diaphanasoma leuchtenbergianum* was found to be much more abundant in past studies.[1,57,58]

4.6.2.4 Benthic macroinvertebrates

Many abiotic and biotic factors, such as current, water chemistry, substrate composition, and trophic dynamics, exert strong influences on benthic community structure.[62-64] In both the Clinch River and Poplar Creek, reservoir construction and the subsequent manipulation of water levels and flows have undoubtedly influenced the composition of these communities in the vicinity of ORGDP.[15,65-67]

Benthic macroinvertebrates collected by Ponar grab sampling from April 1977 through March 1978 were dominated by the phyla Arthropoda (primarily Diptera), Annelida (primarily Oligochaeta), and Mollusca (primarily Pelecypoda). These groups constituted 47%, 38%, and 15%, respectively, of the total number of organisms collected. The Clinch River sites were dominated by oligochaetes (45% of the total number) and dipterans (26%), whereas a converse pattern was evident in Poplar Creek, where dipterans and oligochaetes represented 50% and 37%, respectively, of the total number. The relative contributions of the major taxonomic categories at each sampling site are given in Table 4.18.

Table 4.18. Relative abundance (%) of benthic macroinvertebrates at the six ORGDP sampling sites[a]

	Poplar Creek Mile[b]			Clinch River Mile[b]		
	11.0	5.5	0.5	15.0	11.5	10.5
Diptera						
Chironomidae	43.3	54.4	31.2	32.5	22.3	16.3
Ceratopogonidae	2.6	0.4	2.8	0.5	2.4	
Chaoborus punctipennis		1.2	12.7	0.3	2.1	1.0
Others	0.7	0.4				
Total	46.6	56.4	46.7	33.3	26.8	17.3
Oligochaeta						
Tubificidae	25.4	31.3	34.2	37.3	50.5	43.6
Others	1.0	1.2	0.6	1.4	0.8	1.0
Total	26.4	32.5	34.8	38.7	51.3	44.6
Pelecypoda						
Corbicula manilensis	20.1	0.4	0.5	26.2	8.8	28.7
Others	0.5	3.3	3.6	0.3	0.6	1.0
Total	20.6	3.7	4.1	26.5	9.4	29.7
Ephemeroptera						
Hexagenia limbata		3.3	13.2	0.3	8.7	6.4
Others	1.7			0.3		
Total	1.7	3.3	13.2	0.6	8.7	6.4
Coleoptera						
Dubiraphia	2.2	2.5	0.3		0.5	0.5
Others					0.3	
Total	2.2	2.5	0.3		0.8	0.5
Tricoptera	0.2	0.4		0.6	0.3	1.0
Amphipoda					1.5	
Others[c]	2.3	1.2	0.9	0.3	1.2	0.5

[a] Values were calculated from samples collected on seven dates between April 1977 and March 1978.

[b] Sampling sites are shown in Fig. 4.10.

[c] Includes the following orders: Gastropoda, Hydracarina, Isopoda, Megaloptera, Nematoda, Odonata.

Mean annual densities of the benthos ranged from 412 organisms/m^2 at CRM 10.5 to 856 organisms/m^2 at PCM 11.0. The former value was significantly lower than that at CRM 11.5, the station immediately upstream. Densities at all sites were generally highest from April through September. A large proportion of summer peak densities was due to increases in chironomid (Diptera) populations, whereas high densities in September may be attributable to growth and maturation of tubificids (Oligochaeta) and *Corbicula manilensis* (Mollusca).

The Shannon-Wiener diversity index (H^1) has been used to facilitate interstation comparisons of the low to moderately diverse benthic communities.[1,15,57] Values of H^1 (base e) were below 2.00 in the ORGDP study in all cases. This value signifies a probability of relatively low diversity compared with benthic aquatic communities in general. Diversity at Poplar Creek station PCM 0.5 and Clinch River station CRM 11.5 was relatively high throughout the year as compared with the other study sites.[15]

Of the 67 taxa collected from the study area, 22 were members of Chironomidae (Diptera). Generally, differences in the number of taxa collected at the sampling sites could be attributed to the numbers of chironomid genera found.[15] Four of these genera, *Procladius*, *Polypedilum*, *Cryptochironomus*, and *Tribelos*, collectively accounted for 22% of all organisms. *Procladius* was especially dominant at the two downstream Poplar Creek stations, constituting 38.7% of the benthos at PCM 5.5 and 15.2% at PCM 0.5.[15] Many chironomid genera are common in the diet of bottom-feeding fish in the Clinch River.[57]

The order Oligochaeta (aquatic earthworms; primarily the family Tubificidae) was predominant at all sites throughout the year. The majority of the tubificids were *Limnodrilus, Branchiura sowerbyi*, and sexually immature individuals.

Corbicula manilensis (Mollusca), the Asiatic clam, was the dominant species (by weight) found in the ORGDP study area; it was especially predominant at PCM 11 and at all Clinch River stations. This widely distributed introduced species probably represents the majority of the biomass of Clinch River benthic organisms and is a common component of the diet of many fish species found in the Clinch River.[1,68]

4.6.2.5 Fish

A substantial amount of historical documentation of lower Clinch River fish communities has been produced in the last two decades, including at least ten surveys.[15] Melton Hill and Watts Bar reservoirs have been particularly well-studied, using gill-netting, electroshocking, and cove rotenone collection methods. Differences in community composition as determined in the various surveys are largely attributable to natural variability in the fish populations. However, differences caused by variations in sampling methodology are undoubtedly significant in many cases. A summary and comparison of the previous studies are given by Loar et al.[15]

In the ORGDP monitoring survey,[15] gill netting and electroshocking from April 1977 through March 1978 resulted in the collection of 30 fish species from 10 families. Numerically, Clinch River stations were comprised of 58% game fish, 14% rough fish, and 28% forage fish; Poplar Creek sites harbored 32% game, 23% rough, and 45% forage fish.

Prior to the completion of Melton Hill Dam, the lower Clinch River now included in the resultant impoundment was probably dominated by gizzard shad and rough fishes (e.g., Catostomidae). Significant shifts in the relative abundance of species appear to have occurred after impoundment,[69] including a decrease in the ratio of rough to game fish. Fish communities below Melton Hill Dam have also been subjected to the influences of Watts Bar Reservoir (Sect. 4.4.1.1).

The Clupeidae have generally made up a major portion of the total fish density and biomass in the lower Clinch River, as is typical of southeastern U.S. reservoirs.[70] Two members of this family, threadfin and gizzard shad, are classified as forage fish and have consistently been the most numerous species in collections from the Clinch River in the vicinity of the Oak Ridge Reservation. In recent surveys, shad represented 38% to 74% of the total number of fish collected.[1,15,57] In a 1975-1976 study, threadfin shad were extremely abundant in fall and winter sampling periods, but were much less common during the spring and summer months.[57] This species may exhibit substantial growth during the warmer months, but it is quite sensitive to low temperatures and is therefore subject to high rates of winter mortality.[71,72] The relatively severe winter of 1977 may have substantially reduced the threadfin population in the ORGDP area, thereby accounting for the low number of the species in the 1977-1978 surveys (when they accounted for only 1% of the total, as compared with >33% in previous collections). Historically, threadfin have constituted only a small fraction of the total fish biomass, being predominantly represented by young-of-the-year individuals.[1,57,73-75]

The gizzard shad, which tends to have a more northerly range than the threadfin,[76] was the most common species collected in the ORGDP survey, constituting 24% of the total number collected from the Clinch River and 44% of the total from Poplar Creek; it also accounted for 31% of the total biomass. The average weight of gizzard shad collected in Poplar Creek was considerably greater than the average weight of those in the Clinch River, principally because of the presence of older individuals in the creek during the spawning season.

The distribution of white bass (Percichthyidae) in the ORGDP survey indicates that this species, like gizzard shad, migrates up Poplar Creek to spawn in the spring. Some individuals of both species appear to remain in the creek for extended periods, but the majority of the populations move to the reservoir after spawning.[15] Striped bass, another percichthyid, has been introduced in the ORGDP area, but natural reproduction has not been documented. Yellow bass were also collected in the ORGDP survey, and it appears that this species may be extending its range in the upper sections of Watts Bar Reservoir.[75] Due to the abundance of white bass and gizzard shad, the Percichthyidae and Clupeidae combined accounted for 50% of the total fish biomass in the ORGDP study. Numerical and biomass relative abundances of each family at the six sampling sites are given in Table 4.19.

Table 4.19. Percent abundance, by number and biomass, of adult fish (by families) collected by gill netting and electroshocking at six ORGDP survey sites[a]

	PCM 11.0		PCM 5.5		PCM 0.5		CRM 15.0		CRM 11.5		CRM 10.5	
	Numbers	Biomass	Numbers	Biomass	Numbers	Biomass	Numbers	Biomass	Numbers	Biomass	Numbers	Biomass
Catostomidae	26.3	41.1	6.3	16.5	5.0	16.3	3.1	2.7	2.9	11.4	5.0	25.9
Centrarchidae	9.1	3.7	17.4	4.9	21.8	7.4	21.9	12.5	56.3	36.5	43.4	11.2
Clupeidae	37.4	21.3	53.1	35.0	45.2	36.6	43.8	45.4	20.4	30.7	35.8	46.5
Cyprinidae			3.4	13.0	2.5	4.2	6.2	8.1	1.0	6.6	1.3	1.6
Hiodontidae				•	0.4	0.4			1.0	1.6	2.5	2.7
Ictaluridae			1.9	4.1	5.0	10.8			1.0	0.3		
Lepisosteidae			1.0	5.6	2.9	14.2						
Percichthyidae	23.2	32.7	13.5	18.0	10.0	8.5	17.2	17.9	13.6	7.7	5.7	2.6
Percidae	1.0		1.0	1.4			7.8	13.3	2.9	4.6	3.1	7.6
Sciaenidae	3.0	1.2	2.4	1.4	7.1	1.7			1.0	0.6	3.1	1.9

[a]Sampling sites are shown in Fig. 4.10.

Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

The Centrarchidae has historically accounted for the greatest number of species in recent lower Clinch River surveys; centrarchids were second only to clupeids in the numerical abundance of individuals in the recent survey.[15] Bluegill, largemouth bass, and white crappie accounted for the majority of the family's numbers and biomass, and, along with the percichthyids and sauger (Percidae), they are the most common game fish in the ORGDP area.

The majority of the rough fish in the vicinity of ORGDP are members of the Catostomidae, primarily represented by smallmouth buffalo and silver redhorse. Catostomids were dominant at PCM 11.0 and CRM 10.5, where they represented 41% and 26% of the total biomass respectively. The lower proportion of rough-fish biomass at the two lower Clinch River stations resulted in high representations by game fish (48% of the total at CRM 11.5 and 44% at CRM 10.5).[15]

Metered net surface samples of ichthyoplankton (fish eggs and larvae) were collected at weekly intervals from March through September 1978 in the ORGDP survey.[15] The study was conducted to determine the seasonal occurrence of ichthyoplankton, the spawning success of various adult taxa, and the relative contribution of Poplar Creek to Clinch River populations, since it was hypothesized that a tributary stream might function as a major spawning area for several species of fish. Hess and Winger[77] found that a backwater area of a tributary of the Cumberland River (Tennessee) contained considerably higher densities than the main stream.

Two peaks in larval fish abundance were evident in the ORGDP survey; the first occurred in mid-April, whereas the greater second peak extended from late May through June. Poplar Creek densities were usually substantially higher than those of the Clinch River, except during late April and early May, when both streams displayed similar densities. The highest Poplar Creek densities occurred in late May, when all three sites exceeded 50 larval fish/m^3. At this time, larval abundance was 1 to 2 orders of magnitude higher than it was earlier in the month. Densities among Poplar Creek stations were somewhat similar throughout the collection period.

Peak fish larval densities recorded for the Clinch River occurred in early May, when densities were at or below 1 larval fish/m^3. No samples were collected in late May from the Clinch River. Samples from CRM 15.0 tended to contain the lowest density throughout the season.

A peak in egg density (10 eggs/m^3) occurred at PCM 11.0 in early May, preceding the second larval peak. Eggs were much less numerous at all other sampling sites. This difference may be partially attributable to the fact that the entire water column was sampled at the relatively shallow PCM 11.0 site, whereas only the upper meter was sampled at other stations.

Night sampling of ichthyoplankton at CRM 11.5 and PCM 0.5 was also conducted from May through early July to determine any differences in larval size, abundance, or species composition due to natural temporal fluctuations or gear avoidance.[15]

4.6.3 Rare, threatened, and endangered species

4.6.3.1 Terrestrial species

Plants

Rare, threatened, and endangered plant species native to Roane and/or Anderson counties, Tennessee, are listed in Table 4.20. One endangered and five threatened species occur on the reservation. One of the threatened species, black snakeroot, occurs within 3000 m of the site. Black snakeroot was found at the base of the northwest-facing slope where the slope breaks into the small floodplain of Grassy Creek. This species requires calcareous soils of mesic sites that have undergone minimal modification.

Table 4.20. Native plant species of Roane and/or Anderson counties, Tennessee, that are rare, threatened, endangered, or of special concern

Species	Status[a]	Proximity to ORGDP
Medicus (*Apios priceana*)	E	Oak Ridge Reservation
Bradley's spleenwort (*Asplenium bradleyi*)	R	Roane and Anderson counties
False foxglove (*Aureolaria patula*)	Th	Oak Ridge Reservation
Black snakeroot (*Cimicifuga rubifolia*)	Th	Within 3000-m radius of site
Tall larkspur (*Delphinium exaltatum*)	Sc	Oak Ridge Reservation
Nodding mandarin (*Disporium maculatum*)	R	Anderson County
Purple cone-flower (*Echinaceae purpurea*)	R	Roane County
Large fothergilla (*Fothergilla major*)	R, Sc	Oak Ridge Reservation
Goldenseal (*Hydrastis canadensis*)	R	Oak Ridge Reservation
Canada lily (*Lilium canadense*)	Sc	Oak Ridge Reservation
Ginseng (*Panax quinquefolium*)	R, Th	Oak Ridge Reservation
Sharp's mock-orange (*Philadelphus sharpianus*)	R	Roane and Anderson counties
Gaywings (*Polygala paucifolia*)	R	Roane County
Carey's saxifrage (*Saxifraga careyana*)	Th	Oak Ridge Reservation
Carolina saxifrage (*Saxifraga carolinana*)	Th	Oak Ridge Reservation
Lesser ladies' tresses (*Spiranthes ovalis*)	Sc	Oak Ridge Reservation

[a] E = endangered; R = rare, Th = threatened; Sc = special concern.

Sources:

1. "Report on Endangered and Threatened Plant Species of the United States," presented to the U.S. Congress by the Secretary of the Smithsonian Institution, House Document No. 94-51, 1975.

2. A. J. Sharp, "Rare Plants of Tennessee," *Tenn. Conserv.* XL(7) (1974).

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Animals

Rare, threatened, and endangered wildlife species observed on the reservation are listed in Table 4.21. Although no threatened or endangered species were observed nesting on the site, the bald eagle, an endangered species, was observed along the Clinch River. Sixteen bird species observed on the reservation currently are showing population declines and are on the Audubon Blue List. Due to the high mobility of these species, they will probably use parts of the site area.

No verified evidence of the endangered eastern mountain lion (*Felis concolor*) is available, but 22 unverified sightings during the past decade at various locations on the reservation are known.[78] Most sightings were near ORNL, 7 km (4 miles) east of ORGDP, but three of the sightings occurred within 2 km (1.2 miles) of ORGDP in 1968, 1976, and 1977. A modest program to collect verified evidence (tracks, photographs) of the presence of mountain lions is under

Table 4.21. Rare, threatened, and endangered wildlife species observed on the Oak Ridge Reservation

Species	Status[a]	Local habitats
Canvasback (*Aythya valisineria*)	BL	Lakes, ponds, rivers, marshes
Cooper's hawk (*Accipiter cooperii*)	BL	Open woodlands and edges, groves
Sharp-shinned hawk (*Accipter striatus*)	BL	Open woodlands and edges, forests, thickets
Marsh hawk (*Circus cyaneus*)	BL	Marshes and grasslands
Red-shouldered hawk (*Buteo lineatus*)	BL	Moist woodlands, open woodlands and edges
Bald eagle (*Haliaeetus leucocephalus*)	E	Lakes, rivers
Osprey (*Pandion haliaetus*)	BL	Lakes, rivers
Sparrow hawk (*Falco sparverius paulus*)	BL	Open country, farmlands, roadsides, wooded streams, cities
Barn owl (*Tyto alba*)	BL	Woodlands and edges, groves, fields, farms, towns
Purple martin (*Progne subis*)	BL	Open forests, towns, farms
Bewick's wren (*Thryomanes bewickii*)	BL	Thickets, underbrush, farms, woodlands, fence rows
Eastern bluebird (*Sialia sialis*)	BL	Open country, roadsides, open woodlands
Loggerhead shrike (*Lanius ludovicianus*)	BL	Open country with lookout posts, farmland with scattered trees
Yellow warbler (*Dendroica petechia*)	BL	Stream-side woods of willow and poplars, town, shade trees, swamps, orchards
Grasshopper sparrow (*Ammodramus savannarum*)	BL	Hay fields, weedy fallow fields, grasslands
Henslow's sparrow (*Passerherbulus henslowii*)	BL	Weedy fields
Bachman's sparrow (*Aimophila aestivalis*)	BL	Open pine or oak woods, brushy pastures, abandoned brushy fields, old orchards
Eastern mountain lion (*Felis concolor*)	E	Closed forests

[a]BL = Blue List; E = endangered.

Sources:

1. National Audubon Blue List, *American Birds*, vol. 31, No. 6, 1977.
2. U.S. Department of the Interior, Fish and Wildlife Service, *United States List of Endangered Fauna*, U.S. Government Printing Office, Washington, D.C., 1974.

way.[79] If there are mountain lions near ORGDP, the concentration of fluorides in vegetation and, subsequently, in small mammals (Sect. 5.2.1.1), could be detrimental to this "top predator."

4.6.3.2 Aquatic species

Prior to impoundment, the Clinch River and its tributaries contained several endemic species. These organisms are now largely confined to the unaltered regions, namely, the section above Norris Reservoir. For example, whereas nearly 30 endemic mollusk species have been found above the reservoir, none has been recorded recently below it.[80] Similarly, although the Clinch River system contains several aquatic organisms listed by the federal government[81,82] and the state of Tennessee[83,84] as threatened or endangered, none has been recently collected from the impounded lower section of the river.[80] Moreover, the biological monitoring program conducted in support of this document revealed no threatened or endangered species.[15]

The eight endangered mollusk species inhabiting the upper river system are classified within the Cumberland Plateau faunal group and are generally recognized as requiring unmodified habitats for survival.[80] Similar habitat restrictions influence the distribution of the three threatened fish species: the slender chub [(*Hybopsis cahni*) found in the upper Clinch], the spotfin chub [(*Hybopsis monacha*) found in the Emory River, a mountain tributary to the lower Clinch], and the yellowfin madtom [(*Noturus flavipennis*) restricted to tributaries of the upper Clinch]. Portions of these streams are designated as critical habitats for these species.[85]

One mollusk species from the lower Clinch, *Leptodea leptodon*, was described as rare in a 1971 symposium, but it has not as yet obtained legal endangered status and it has not been recorded in the area for several decades.[80,86]

It appears that the major reason for the decline of the listed endangered and threatened species has been the impoundment of the river system.[67] Thus, it is unlikely that ORGDP has had or now has an appreciable effect on the survival of any of these species.

4.7 REGIONAL LANDMARKS

4.7.1 Historical landmarks

The National Register of Historic Places[87] lists 23 sites in the five-county area (Anderson, Knox, Loudon, Morgan, and Roane) around ORDGP, only four of which occur within a 16-km (10-mile) radius of the plant site. The Graphite Reactor at ORNL is listed in Anderson County,[88] although it is in Roane County, 7 km (4 miles) east of ORGDP. The site houses the world's first full-scale nuclear reactor, the first reactor to produce significant amounts of heat as well as measurable amounts of plutonium-239.

Harriman City Hall [15 km (9 miles) from ORGDP], Roane County Courthouse in Kingston [15 km (9 miles)], and Southwest Point at the confluence of the Clinch and Tennessee rivers [16 km (10 miles)] are Roane County listings in the National Register. More information on historical places and structures of local significance is available in ref. 1. A 1975 study of ORDGP[89] indicated that no other historical structures or sites require preservation or mitigation of adverse impacts under federal criteria.[87]

4.7.2 Archaeological sites

Recent field studies and reconnaissance[87,90] revealed 45 sites of prehistoric occupation, including a paleo-Indian site, eight Archaic Period sites, 24 Woodland Period sites, and 5 Mississippian Period sites. Most of these sites were distributed along the Clinch River mainstream. It was concluded that at least 12 sites located in and around ORGDP could be affected by new construction at the site, but that they are unlikely to require attention during normal operations.[90] Subsequent studies confirmed this conclusion.[89]

4.7.3 Cultural landmarks

The American Museum of Science and Energy (formerly the American Museum of Atomic Energy) is located in Oak Ridge, 14 km (9 miles) northeast of ORGDP. The $3.5 million building, which houses displays, movies, demonstrations, and equipment on energy, recorded 285,000 visitors during FY 1978. The Graphite Reactor is described in Sect. 4.7.1. The ORGDP itself attracts many visitors who view it from an enclosed and well-equipped overlook along the Oak Ridge Turnpike (state Rt. 58). The University of Tennessee maintains one of the Southeast's largest and most complete collections of Appalachian plant species at the UT Arboretum, 16 km (10 miles) east-northeast of ORGDP. The arboretum is heavily used throughout the year.

4.8 COMMUNITY CHARACTERISTICS

Anderson County. Anderson County (1970 population: 60,300) includes two distinct population groups because of the unique way in which the city of Oak Ridge was formed. In the 1940s, the federal government acquired about 58,000 acres of rural Tennessee land for weapons development during World War II. Part of the land, originally set aside for the residential, commercial, and support services needed by the government employees, became the self-governing city of Oak Ridge in 1959. Although the entire original "Oak Ridge Reservation" is designated as the city of Oak Ridge, about 37,300 acres remain under DOE's control.

The Anderson County population, excluding Oak Ridge, has much in common with the surrounding rural Tennessee population. Oak Ridge, on the other hand, has demographic characteristics that set it apart from other communities in the area and from the rural population. For example, in 1970, Anderson County had a rural black population of 228 (less than 1%), which is similar to the rural population of the region. Even though only 5.5% of Oak Ridge citizens are Blacks, Oak Ridge contains over 75% of all Blacks in Anderson County. Other differences between the two populations include: (1) Anderson County residents outside Oak Ridge are more evenly distributed by age groups, whereas Oak Ridge has proportionately more working-age and proportionately fewer retirement-age people; (2) only 52.8% of Oak Ridge's citizens are native Tennesseans, compared with 85.9% native Tennesseans in the rest of Anderson County; and (3) virtually all foreign-born residents in Anderson County live in Oak Ridge.

The creation of Oak Ridge was the main contributing factor in the urbanization of the previously rural area. Population growth in Anderson County was most dramatic between 1940 and 1950 as a consequence of the establishment of the federal reservation. Between 1950 and 1970, the population has increased only from 59,407 to 60,300.

Knox County. Knox County, including the city of Knoxville, is the population and service center of the region. Knox County has grown steadily from 250,523 in 1960 to 276,293 in 1970 and to an estimated 310,000 as of November 1976. The western part of Knox County (from the city of Knoxville toward the DOE Reservation) is currently the main growth area. This growth is due to a variety of factors, including easy access by I-40 to either Knoxville or the Oak Ridge Reservation, availability of developable land, and employment opportunities provided directly and indirectly by DOE, TVA, and The University of Tennessee. Recent ORGDP employment statistics indicate that Knoxville, as a place of residence, is attracting a larger share of new employees than any other area, although Oak Ridge still accounts for the largest group of employees, with 1660 of the 6082 employed in 1976 residing in Oak Ridge.

Roane County. Roane County's population (1975 estimated: 40,600) currently is slowly but steadily increasing and changing from a rural to an urban type. Urban areas, which account for 53.5% of the population, include Harriman (8734), Kingston (4142), Rockwood (5259), and parts of Oliver Springs and Oak Ridge.

Loudon County. Loudon County is a small, predominantly rural county with two small cities, Lenoir City and Loudon. The county has grown from 24,266 in 1970 to an estimated 26,300 in 1975, with about equal growth in both urban and rural areas.

Morgan County. Morgan County is the largest of the five counties in land area, but the smallest in population (1970 population: 13,619). Except for a small part of Oliver Springs (34 people), all of Morgan County is classifed as rural.

Current DOE profile in communities

The development and operation of the DOE installations (previously the Manhattan Project, U.S. AEC, and ERDA) have greatly influenced the region. The plants have recruited numerous workers from outside the region, created long-term permanent employment for many local citizens, contributed to the development and growth of towns and cities, and affected the operation of a variety of social and political institutions.

Employment in the energy program at Oak Ridge is divided among DOE (prior to Febraury 1975, the Atomic Energy Commission; from February 1975 to October 1977, ERDA) and its prinicpal operating contractors: Union Carbide Corporation, Nuclear Division (UCC-ND), which operates the Oak Ridge Gaseous Diffusion Plant (ORGDP), the Oak Ridge Y-12 Plant, and the Oak Ridge National Laboratory (ORNL); Oak Ridge Associated Universities (ORAU); and The University of Tennessee, which operates the Comparative Animal Research Laboratory (CARL).

Overall, the three major installations operated by UCC-ND under contract with DOE have provided a stable source of employment for 30 years, averaging about 13,000 employees annually (Table 4.22). These figures do not include the people employed to construct the plants; at the peak construction period in mid-1945, an estimated 70,000 workers were involved in the construction of the three plants.

Table 4.22. Yearly average employment at ORGDP, ORNL, and Y-12, 1943 to 1976

	1943	1947	1952	1955	1958	1960	1963	1966	1969	1973	1974	1975	1976
ORGDP	4,900	4,900	4,900	4,280	4,952	4,150	2,700	2,570	2,750	3,000	4,300	5,000	6,000
ORNL	3,000	3,000	3,000	3,120	3,735	4,200	4,480	5,190	5,100	4,100	4,500	5,000	5,200
Y-12	3,560	3,560	3,560	3,560	6,225	5,203	5,420	4,440	5,400	6,000	5,400	5,000	4,800
Total	11,460	11,460	11,460	10,960	14,912	13,553	12,600	12,200	13,250	12,100	14,200	15,000	16,000

Source: C. R. Meyers, Jr., *Spatial Distribution and Employment Trends of Manufacturing Industries in East Tennessee, 1943–1973*, ORNL/NSF/EP-38, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1974, pp. 16–17.

Aesthetic, recreational, and cultural values

Refer to Sect. 4.2 for coverage of residential land use and demography, industrial land use, recreational land use, and public facilities and to Sect. 4.7 for historical landmarks, archaeological sites, and cultural landmarks.

Ambient noise

Operations at the ORGDP site do not result in noise levels that affect the surrounding community. Noise from diesels, generators, and heavy equipment is localized within the perimeters of the plant. Additionally, the site is sufficiently isolated from residential, commercial, and recreational areas to preclude adverse effects from noise.

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5. ENVIRONMENTAL CONSEQUENCES

5.1 HUMAN ENVIRONMENT

5.1.1 Socioeconomic

The Oak Ridge Gaseous Diffusion Plant (ORGDP), along with the other U.S. Department of Energy (DOE) facilities, has major local impacts in two ways: by providing a major source of employment in the region and by restricting the tax bases of Anderson and Roane counties (Fig. 4.1). Although the facilities have had a positive impact on local employment, they have had minimal impact on hard-core unemployment and a mixed positive and negative impact on new industrial development.

The DOE installations occupy 6% of the total land area of Anderson County and 10% of that of Roane County. This acreage includes many of the prime industrial sites in the two counties, including frontage on the Tennessee Valley Authority's (TVA) Melton Hill and Watts Bar lakes. Although industrial sites are available off the reservation, the size of the reservation and its location have limited the site possibilities for new private industries. The presence of the DOE facilities has resulted in the formation of some local "spin-off" industries, as well as the location of some consulting firms in the area. It is beyond the scope of this statement to determine a balance of the positive and negative impacts on local industrial development.

The large facilities operated by DOE, DOE contractors, and TVA are exempt from ad valorem property taxes because they are federally owned. This tax-exempt status, along with changes in financial assistance under the Atomic Energy Community Act of 1955, continues to be the subject of much debate in the local area. This substantially reduces the size of the potential tax bases for the two counties in which the facilities are located, bringing the contention that the restricted tax bases result in excessive property taxes on residences, farms, and small businesses in attempts by local governments to meet service needs caused by the large number of employees from the facilities.

Tax statistics show that Anderson County continues to have the highest actual and effective property tax rates of any Tennessee county.[1,2] Several studies on these issues have been undertaken, but there has been no satisfactory resolution.[3-5] Although these issues are important locally, and may result in disassociation of costs and benefits to local populations, the socioeconomic costs associated with the tax-exempt status of the facilities and the benefits associated with federal assistance payments are not considered in this study (see Sect. 10).

For the past 30 years, ORGDP has provided a major source of employment. These employees have greater average income in their respective localities, enjoy a relatively higher standard of living than is customary for the area, and contribute more per capita to the local economy than the average, thereby providing an important source of local revenue.

5.1.2 Human health and radiological dose

5.1.2.1 Assumptions for radiation exposure resulting from routine operation

Radiation-exposure pathways

Environmental transport links the source of release to the receptor by numerous exposure pathways. Figure 5.1 is a diagram of the most important pathways that result in the exposure of man to radioactivity released to the environment. The resulting radiation exposures may be either external or internal. External exposures occur when the radiation source is outside the irradiated body, and internal exposures are those from radioactive materials within the irradiated body.

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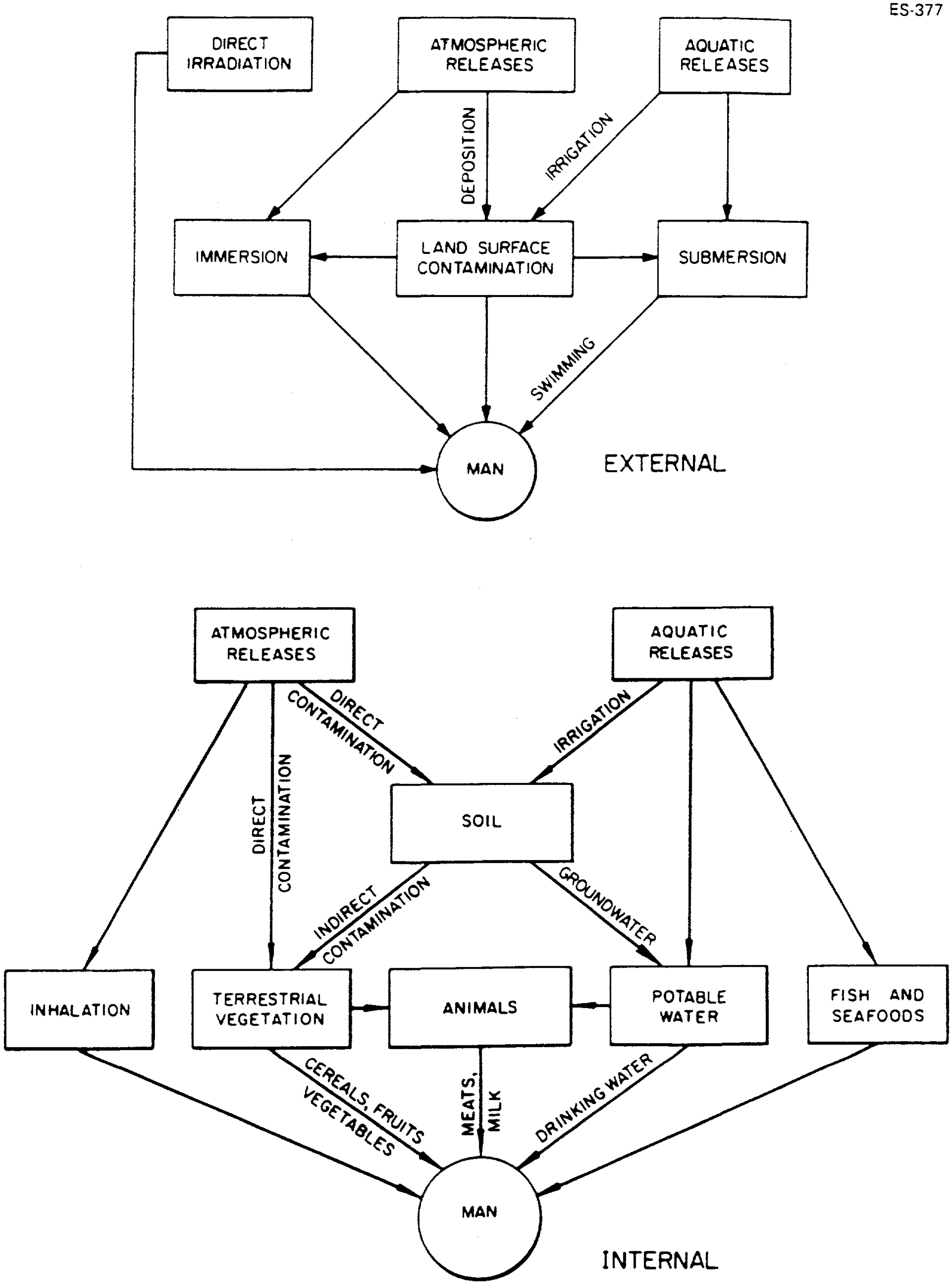

Fig. 5.1. Pathways for exposure of man from releases of radioactive effluents.

Releases of radioactive gases and particulates to the atmosphere may result in external doses by exposure to and/or immersion in the plume and to a contaminated land surface; internal doses result from inhalation and ingestion. Man immersed in a radioactive plume receives an external immersion dose and also an intake of radioactivity by inhalation as long as the plume or the suspended radionuclides are present. Deposition of radionuclides from the plume onto vegetation and onto soil creates the possibility of external exposure from the contaminated surface and of internal exposure via the food chain.

Releases of radioactive liquid effluents to the environment may result in external exposure of man by submersion in water during swimming or bathing and by exposure to a contaminated shoreline or to emergent sediments in a tidal area (Fig. 5.1). Aquatic releases may also result in exposure of man through numerous food-chain pathways.

Additional external irradiation of man is possible from exposure at some distance by gamma radiation. Pathways that exemplify this type of direct radiation exposure include plume overpassage, boating on or standing near a body of contaminated water, gamma radiation that penetrates shipping containers, and medical x rays.

Estimation of radiation doses

Radiation doses are estimated per year of plant operation for normal releases for both individuals and the population that lives within 50 miles of a facility. The assumptions and dose models used are identified with appropriate citations in the following sections. Additional details, listings of computer codes, tables of dose conversion factors, and sample calculations are given elsewhere.[6,7]

External exposure. The doses from external exposure to radionuclides resulting from airborne releases were calculated using AIRDOS-II.[8] Factors for converting external radiation exposures to dose were obtained with the computer code EXREM III[9] and incorporated into the AIRDOS-II computer code. The dose rate above the contaminated land surface is estimated for a height of 100 cm. Following the initial deposition of radionuclides, the potential for exposure of man may persist — depending on the influence of environmental redistribution — long after the plume leaves the area. Concentrations of radionuclides at the point of deposition normally are reduced by infiltration of the radionuclides into the soil, by loss of soil particles due to erosion, and by transport in surface water and in groundwater. When the effects of these processes cannot be quantified, a conservative estimate of dose due to external exposure to the contaminated surface is obtained by assuming that the radionuclide concentrations are diminished by radioactive decay only.

The models for immersion in air and for submersion in water are based on the assumption that the entire body surface is in contact with a large volume of contaminated air or water. For all external exposures, dose estimates for the various internal organs include contributions due to photon irradiation only.

Internal exposure. Factors for converting internal radiation exposure to estimates of dose were computed and summarized by the INREM-II computer code,[10] implementing recent models.[11,12] Details of these models and assumptions are described by Dunning et al.[7] The dose conversion factors used are presented in Tables 5.1 and 5.2. These factors were input data into the AIRDOS-II code,[8] which was used to make the calculations for inhaled and ingested radionuclides. Internal exposure continues as long as radioactive material remains in the body, which may be longer than the duration of the individual's residence in the contaminated environment. The best estimates of internal dose resulting from an intake are obtained by integrating over the remaining lifetime of the exposed individual; such estimates are called "dose commitments." The remaining lifetime is assumed to be 50 years for an adult. Throughout the text and tables, "dose" means "dose commitment" whenever contributions from internal-exposure pathways are included.

Man's dietary intake of deposited radionuclides is predicted with an expansion of the "terrestrial vegetation" and "animals" boxes in Fig. 5.1. The resulting model,[13] a simplification of a real terrestrial food-pathway system, is incorporated into the computer code TERMOD, which is used to obtain information on food-chain transfers to man prerequisite to calculation of internal dose. The terrestrial food-chain model provides predictions of radionuclide intakes by man through consumption of milk, beef, and plants contaminated by direct deposition as well as by uptake from the soil. This generalized dynamic model is sufficiently versatile to be applied

Table 5.1. Dose conversion factors[a] used in the radiological assessment of ORGDP airborne releases — inhalation

Radionuclide	Dose conversion factor (rems/μCi)[b]			
	Total body	Bone	Lungs	Kidneys
Tc-99	1.73E−4[c]	2.66E−4	1.64E−3	3.38E−4
U-234	1.92E1[d]	2.21E2	8.04E−1	9.44
U-235	1.73E1	2.00E2	7.34E−1	8.54
U-236	1.81E1	2.09E2	7.59E−1	8.90
U-238	1.70E1	1.96E2	7.17E−1	8.49

[a] From D. E. Dunning, Jr., et al., *Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities,* vol. II, ORNL/NUREG/TM-190, Oak Ridge National Laboratory, Oak Ridge, Tenn. (to be published); other pertinent dose conversion factors used for external dose calculations can be found in G. G. Killough and L. R. McKay, eds., *A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment,* ORNL-4992, Oak Ridge National Laboratory, Oak Ridge, Tenn., March 1976.

[b] Based on all airborne radionuclide particles being 0.3 μm in size and soluble.

[c] Read as 1.73×10^{-4}.

[d] Read as 1.92×10^{1}.

Table 5.2. Dose conversion factors[a] used in the radiological assessment of ORGDP airborne releases — ingestion

Radionuclide	Dose conversion factor (rems/μCi)[b]			
	Total body	Bone	Lungs	Kidneys
Tc-99	2.14E−4[c]	3.61E−4	2.14E−4	4.58E−4
U-234	1.73	1.99E1[d]	8.23E−4	8.51E−1
U-235	1.56	1.80E1	1.37E−3	7.71E−1
U-236	1.63	1.88E1	7.77E−4	8.02E−1
U-238	1.54	1.76E1	8.04E−4	7.65E−1

[a] From D. E. Dunning, Jr., et al., *Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities,* vol. II, ORNL/NUREG/TM-190, Oak Ridge National Laboratory, Oak Ridge, Tenn. (to be published); other pertinent dose conversion factors used for external dose calculations can be found in G. G. Killough and L. R. McKay, eds., *A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment,* ORNL-4992, Oak Ridge National Laboratory, Oak Ridge, Tenn., March 1976.

[b] Based on all airborne radionuclide particles being 0.3 μm in size and soluble.

[c] Read as 2.14×10^{-4}.

[d] Read as 1.99×10^{1}.

to many terrestrial environments and to all radionuclides. The estimations of doses to man via ingestion of water and fish are based on the assumption that the radionuclides released in liquid effluents are diluted in the receiving water body before the water and fish are consumed.

Radiation dose to an individual. Dose is estimated for individuals located at the site boundary for the most significant exposure pathways. The location of potential maximum exposure is identified and evaluated; that location is assumed to have the highest concentration of radionuclides in the surrounding air and on the land surface. Further assumptions are that the exposed individual resides continuously at the location (no allowance is made for protective shielding provided by a residence), and that the location is the point of origin for all foods.

All dose estimates given are for adults, unless otherwise specified. Estimates of dose are made for total body and for a number of reference organs, and those radionuclides that contribute large fractions of the total dose are identified. Where significant, the estimates of dose to particular organs are discussed.

Radiation dose to the population. The total dose received by an exposed population due to releases from ORGDP was estimated by summation of individual dose estimates within the population. The area within 50 miles of the plant was divided into 16 sectors (22.5° each) and into a number of annuli. The average dose for an individual in each division was estimated, that estimate was multiplied by the number of persons in the division, and the resulting products were summed across the entire area. Unless otherwise specified, the dose estimates summed are those for total body, and the unit used to express population dose is man-rem. Population dose estimates were calculated for a population assumed to be composed entirely of adults; the estimates are only for those exposure pathways known to involve a significant number of persons. Unique aspects of a specific man-rem estimate are discussed in conjunction with estimates of individual dose for that particular exposure pathway.

5.1.2.2 Impacts from airborne effluents

Doses to the individual. Quantities of radionuclides released to the atmosphere from ORGDP are listed in Table 5.3. A release height of 12 m was assumed for the roof vents of ORGDP; no plume rise was considered. Soluble particles of 0.3 μm were assumed.

Table 5.3. Quantities of radionuclides released to the atmosphere from ORGDP (1984 operation)

Radionuclide	Quantity (Ci)
Tc-99	2.0E−6[a]
U-234	5.5E−4
U-235	1.7E−5
U-236	9.0E−7
U-238	9.0E−5

[a] Read as 2.0×10^{-6}.

Estimated maximum annual total-body and organ doses to individuals from these airborne effluents are shown in Table 5.4. The highest estimated dose occurs at the boundary fence, about 2.5 miles southwest of the plant. The maximum estimated total-body dose is 3.7×10^{-3} millirem per year, of which uranium-234 and -238 contributed 82% and 13% respectively. The highest estimated organ doses are to the bone (4.1×10^{-2} millirem per year) and the kidney (1.9×10^{-3} millirem per year), primarily due to uranium-234 via the ingestion pathway (85% for bone and 80% for kidney).

All annual doses are well below the present NRC limits (10 CFR Part 20) of 500 millirems to the total body, 3000 millirems to the bone, and 1500 millirems to the lungs and kidney. Additionally,

Table 5.4. Contribution of radionuclides to the estimated maximum annual total-body and organ doses to individuals from ORGDP airborne effluents

Radionuclide	Dose[a] (millirem)				
	Total body	Bone	Kidney	Lung	GI tract
Tc-99	2.5E−8[b]	4.2E−8	5.3E−8	2.5E−8	3.7E−7
U-234	3.0E−3	3.5E−2	1.5E−3	3.0E−5	1.4E−4
U-235	1.7E−4	1.1E−3	1.0E−4	7.4E−5	5.1E−5
U-236	4.9E−6	5.6E−5	2.4E−6	3.8E−8	2.2E−7
U-238	4.9E−4	5.3E−3	2.5E−4	3.1E−5	4.0E−5
	3.7E−3	4.1E−2	1.9E−3	1.4E−4	2.3E−4

[a] At or near the ORGDP boundary.
[b] Read as 2.5×10^{-8}.

all annual doses are below future EPA standards (40 CFR Part 190): 25 millirems to the total body, 75 millirems to the thyroid, and 25 millirems to all other organs. The 50-year dose commitments resulting from the release of radioactive materials are based on both the annual average release rates from the plant effluents, which may varying during the year, and on the average annual meteorology of the site, which includes the periods of inversion. The dose commitments are based primarily on the maximum airborne concentrations which occur in the prevailing wind direction at the site boundary, 4500 m from the point of release. Based on Turner's data[14] for χ/Q values for a 10-m release height at a distance of 4500 m, it is estimated that during a period of inversion (F stability) the dose would be about 15 times the dose resulting from a neutral meteorological condition (D stability). Accordingly, the highest 50-year dose commitment occurring during a period of inversion would be less than 1 millirem (see Table 5.4).

Table 5.5 shows the contributions of the major exposure modes to the maximum annual total-body and organ dose estimates. Ingestion is the predominant exposure pathway for the total body and all organs except the lung, which receives its highest dose from contaminated surfaces.

Table 5.5. Contribution of major modes of exposure to the estimated maximum annual total-body and organ doses to individuals from ORGDP airborne effluents

Exposure mode	Dose[a] (millirem)				
	Total body	Bone	Kidney	Lung	GI tract
Inhalation[b]	5.2E−4[c]	6.0E−3	2.6E−4	2.2E−5	3.8E−7
Submersion in air[d]	1.1E−10	1.6E−10	7.3E−11	8.8E−11	5.6E−11
Contaminated ground[d]	1.4E−4	2.2E−4	9.4E−5	1.1E−4	7.2E−5
Ingestion[e]	3.0E−3	3.5E−2	1.5E−3	1.5E−6	1.6E−4
	3.7E−3	4.1E−2	1.9E−3	1.4E−4	2.3E−4

[a] At or near the ORGDP boundary.
[b] Inhalation rate of 23 m^3 of air per day; inhaled particles <10 μm in diameter.
[c] Read as 5.2×10^{-4}.
[d] Exposure is for 100% of time; no shielding.
[e] All food is assumed to be produced and consumed at the location of dose calculation; daily intakes are 0.25 kg of vegetables, 0.3 kg of beef, and 1.0 liter of milk.

Doses to the population. The population dose estimates for distances out to 50 miles from ORGDP are shown in Tables 5.6 and 5.7. The estimated total-body dose is 4.4×10^{-2} man-rem, which is principally due to ingestion. This value is substantially lower than the 68,300 man-rem dose to the same population, which results from the natural background of the state of Tennessee.[15] The highest annual organ doses are 4.9×10^{-1} man-rem to the bone and 2.2×10^{-2} man-rem to the kidney, due primarily to ingestion of uranium-234.

Table 5.6. Contribution of radionuclides to estimated annual population doses[a] from ORGDP airborne effluents

Radionuclide	Dose (man-rem)				
	Total body	Bone	Kidney	Lung	GI tract
Tc-99	2.6E−7[b]	4.4E−7	5.6E−7	2.7E−7	3.9E−6
U-234	3.6E−2	4.1E−1	1.8E−2	3.2E−4	1.7E−3
U-235	2.2E−3	1.4E−2	1.3E−3	1.0E−3	6.8E−4
U-236	5.8E−5	6.6E−4	2.8E−5	3.8E−7	2.7E−6
U-238	5.9E−3	6.3E−2	3.0E−3	4.1E−4	5.1E−4
	4.4E−2	4.9E−1	2.2E−2	1.7E−3	2.9E−3

[a]Population of 678,053 persons within 50 miles of ORGDP.
[b]Read as 2.6×10^{-7}.

Table 5.7. Contribution of major exposure modes to estimated annual population doses[a] from ORGDP airborne effluents

Exposure mode	Dose (man-rem)				
	Total body	Bone	Kidney	Lung	GI tract
Inhalation	4.6E−3[b]	5.3E−2	2.3E−3	1.9E−4	3.3E−6
Submersion in air	9.3E−10	1.4E−9	6.5E−10	7.8E−10	4.9E−10
Contaminated ground	2.0E−3	3.0E−3	1.3E−3	1.5E−3	9.7E−4
Ingestion	3.8E−2	4.3E−1	1.9E−2	1.9E−5	2.0E−3
	4.4E−2	4.9E−1	2.2E−2	1.7E−3	2.9E−3

[a]Population of 678,053 persons within 50 miles of ORGDP.
[b]Read as 4.6×10^{-3}.

Radiological health effects. Health effects (cancers) are estimated from the population dose commitments for the regional population (within 80 km). The linear dose-effect relationship derived from the BEIR report[16] by the EPA[17,18] was used to estimate the health effects. The radiological health effects are quite low, the total health effects for the total body being only 0.00007% of that from the comparable background radiation health effects. Table 5.8 summarizes the health effects.

5.1.2.3 Impacts from liquid effluents

The radiological impact of liquid effluents from ORGDP was assessed by calculating the dose to individuals from the use of Poplar Creek and Clinch River waters.

Effluents containing waste radionuclides are discharged into Poplar Creek near its junction with the Clinch River and directly into the Clinch River at a point downstream from the Poplar Creek

Table 5.8. Calculated radiological health effects to the population within 80 km of ORGDP

Organ	Total health effects (cancers)[a]	Fatal health effects (cancers)[b]
Total body	2E−5	9E−6
Lung	7E−8	7E−8
Bone	2E−5	8E−6

[a]Based on EPA dose-effect conversion factors of 400 per 10^6 man-rems for total body, 40 per 10^6 man-rems for lungs, and 32 per 10^6 man-rems for bone.

[b]Based on dose-effect conversion factors of 200 per 10^6 man-rems for total body, 40 per 10^6 man-rems for lung, and 16 per 10^6 man-rems for bone.

junction. The annual release of radionuclides and the resulting concentrations in Poplar Creek and the Clinch River are shown in Table 5.9.

The aquatic pathways (Fig. 5.1) considered in calculating the dose to the individual included submersion in water (swimming) for 1% of the year, ingestion of fish (20 g per day), and ingestion of drinking water (1.2 liters per day). Further assumptions, models, and codes used to estimate radiation doses from contaminated liquid effluents are given in ref. 6.

Table 5.9. Annual release of radionuclides in the liquid effluents and concentrations[a] in Poplar Creek and Clinch River at ORGDP

Radionuclide	Annual release (μCi/year)		Concentration[b] (μCi/ml)	
	Poplar Creek	Clinch River	Poplar Creek	Clinch River
U-234	1.9E5[c]	5.0E3	9.6E−10[d]	1.1E−12
U-235	9.0E3	3.0E2	4.6E−11	6.8E−14
U-236	3.0E3	5.0E1	1.5E−11	1.1E−14
U-238	1.3E5	4.5E1	6.6E−10	1.0E−14
Tc-99	3.0E6	3.0E4	1.5E−8	6.8E−12

[a]The annual flow of Poplar Creek at ORGDP is 1.97E14 ml per year. The flow of the Clinch River at ORGDP is 4.40E15 ml per year.

[b]Assumes complete mixing in the streams at the point of dose calculations.

[c]Read as 1.9×10^5.

[d]Read as 9.6×10^{-10}.

The annual total-body and organ doses estimated for aquatic pathways associated with the Clinch River at ORGDP are summarized in Table 5.10. The table shows the cumulative impact from discharges of radionuclides that first go into Poplar Creek and then to the Clinch River and those that go directly into the river (see Table 5.9).

The primary exposure pathway for total-body dose was the ingestion of drinking water (84%), due primarily to the uranium-234 (60%) and -238 (35%) radionuclides. Eating fish taken from the river at the point of maximum dose calculation was responsible for 14% of the dose. The dose from swimming contributed <1% of the total-body and organ doses. The highest organ doses were to the bone (5.0×10^{-4} millirem per year) and kidney (1.3×10^{-4} millirem per year). All other organ doses were equal to or less than the total-body dose. Doses from all aquatic pathways to the total body and organs were well below 1 millirem per year and did not add significantly to the total dose of the individual.

Table 5.10. Annual doses[a] to the individual from the liquid effluents[b] released from ORGDP into the Clinch River

Pathway	Dose (millirem/year)		
	Total body	Bone	Kidney
Submersion in water[c]	1.7E−9[d]	2.5E−9	1.1E−9
Eating fish[e]	4.5E−6	7.2E−5	1.9E−5
Drinking water[f]	2.7E−5	4.3E−4	1.1E−4
	3.2E−5	5.0E−4	1.3E−4

[a] Fifty-year dose commitments from one year's intake.
[b] Includes effluents discharged directly into the river and those by way of Poplar Creek.
[c] Swimming in the water 1% of the year.
[d] Read as 1.7×10^{-9}.
[e] Daily intake of 20 g of fish caught in the river.
[f] Daily intake of 1.2 liters of untreated drinking water taken from the river.

Poplar Creek from the point where radioactive liquid waste is discharged to its junction with the Clinch River is almost entirely within the confines of the plant-controlled boundary. Thus, little, if any, fishing, swimming, or use of the stream as a source of drinking water is likely until the creek joins the river, where it is diluted further. However, fish may move from Poplar Creek into the river, and some recreation may take place near the mouth of the creek. In Table 5.11, doses are given for all aquatic pathways. The doses from this highly unlikely maximum use of the stream are well below 1.0 millirem per year for the total body and all organs.

Table 5.11. Annual doses[a] to the individual from the liquid effluents released from ORGDP into Poplar Creek

Pathway	Dose (millirem/year)		
	Total body	Bone	Kidney
Submersion in water[b]	1.2E−6[c]	1.7E−6	7.8E−7
Eating fish[d]	6.0E−3	9.8E−2	2.7E−2
Drinking water[e]	3.7E−2	5.9E−1	1.0E−1
	4.3E−2	6.9E−1	1.3E−1

[a] Fifty-year dose commitments from one year's intake.
[b] Swimming in the water 1% of the year.
[c] Read as 1.2×10^{-6}.
[d] Daily intake of 20 g of fish caught in the stream.
[e] Daily intake of 1.2 liters of untreated drinking water taken from the stream.

All doses from either the Clinch River or Poplar Creek are well below the future EPA limits of 25 millirems per year for the total body, bone, and kidneys (40 CFR Part 190). In fact, the highest dose received — 0.69 millirem per year (bone dose from Poplar Creek water use, Table 5.11) — was only 3% of this limit.

5.1.2.4 Impacts from burial grounds

As described in Sect. 2.2.3.3, prior to 1975, about 14 Ci of solid waste containing low-level uranium and thorium had been buried at an ORGDP burial ground. The worst impact this radioactive waste could conceivably have would be its release into a drinking-water supply. It is assumed that the 14 Ci is leached into the nearby Clinch River during one year, an unlikely occurrence. Assuming a dilution factor of 4.1×10^{15} ml/year by the river, a dose conversion factor for the critical organ of 8.292×10^{-1} rem/μCi (bone)[6] for uranium-234 (to maximize the impact), and a 1.2-liter/day consumption rate, the highest dose a person could receive would be 1.24 millirems/year.

The classified burial ground (Sect. 2.2.3.3) contains 0.1 Ci of low-level, uranium-contaminated, nontoxic scrap metal. If it is assumed that this 0.1 Ci of uranium (as uranium-234) is leached over a period of one year into the Clinch River (an unlikely event), the maximum critical organ dose from drinking 1.2 liters/day of the contaminated water would be about 0.01 millirem/year to the bone.

The new burial ground at the Y-12 Plant, which receives ORGDP solid radioactive waste, will be described in an assessment of Y-12 activities, currently being prepared.

5.2 ECOLOGICAL ENVIRONMENT

5.2.1 Terrestrial

If operations at ORGDP induce measurable impacts on terrestrial biota, the impacts will be due to atmospheric chemical releases from process buildings and from cooling towers. The effects of atmospheric pollutants are assessed individually below.

Fluorides. The most likely cause of impacts among the atmospheric pollutants released at ORGDP is fluorides (Sect. 5.3.1). Average air concentrations of hydrogen fluoride (HF) in excess of threshold values for sensitive plants (Table 5.12) will not occur inside (Sect. 5.3.1) nor outside the plant boundary (Table 5.13). During short-term (4-hr) episodes of stable atmospheric conditions (Sect. 5.3.1), concentrations exceeding state air quality standards would be unlikely (Table 5.25, Sect. 5.3.1). None of the simulated concentrations beyond reservation boundaries approaches dosage levels (0.5 μg/m^3) at which vegetation damage occurs (Table 5.25). Field studies were initiated to assess the impacts of fluorides on plants and animals on the reservation,[19] in order to confirm the air quality estimates.

Twenty-eight sampling stations were arranged along four transects which were centered at ORGDP (Fig. 5.2). Vegetation was collected within a circle of 10-m radius during May and early June of 1977 at each site. Small mammals were trapped with 10 Sherman live traps between May 1 and 14 and between August 1 and 14, 1977, at each site. Control samples of vegetation and small mammals were collected 11 km (7 miles) east of ORGDP in an area removed from fluoride contamination. The leaves of plants and the femurs of small mammals were analyzed for fluoride content.

Control vegetation samples contained no more than 7 ppm fluoride. Other work[20] indicates that 10 ppm is a "normal" value for uncontaminated vegetation. The vegetation samples collected furthest from ORGDP (lines A-G, Fig. 5.2, ≥2000 m from HF sources) contained average fluoride values below the normal values (average, 6 ppm; range, 2 to 29.6 ppm). The fluoride content of vegetation was greater near the HF sources:

Distance from source (m)	Average fluoride content (ppm)	Range of fluoride content (ppm)
∿200	22.78	6.2 to 57.8
∿500	14.91	2.8 to 24.1
∿1000	14.96	1.9 to 27.7

Thus, a clear gradient was found, with background values for the fluoride content of vegetation occurring beyond 1000 m from the fluoride sources. Apparent damage to loblolly pine needles was observed in trees ∿200 and ∿500 m from the fluoride source. These needles contained 50 to 80 ppm fluoride, in part confirming the fluoride damage diagnosis. The staff concludes that vegetation damage by fluorides is likely to be common within 500 m of the plant and that it probably is insignificant beyond about 2000 m of the plant.

Table 5.12. **Relative sensitivity of leaves of selected plant species to atmospheric pollutants**

		Pollutant		
		HF	NO_x (PAN)[a]	SO_2
		Crops		
Alfalfa	*Medicago sativa* L.	I[b]	S[b] to I	S
Clover	*Trifolium* spp.	I		S
Soy bean	*Glycine max.* Merr.	R[b]	I	S
Tobacco	*Nicotiana glutinosa*	R	S to I	S
Wheat	*Triticum* spp.	R	R	S
Orchard grass	*Dactylus glommerata*		S	I
Kentucky bluegrass	*Poa pratensis*		R	I
		Garden vegetables		
Bean	*Phaseolus vulgaris* L.	R	R	S
Table beet	*Beta vulgaris* L.		S to I	S
Pumpkin	*Cucurbita pepo*	R	R	S
Sweet corn	*Zea mays*	S	R	R
Tomato	*Lycopersicon esculentum*	R	I to R	I
		Forest species		
Eastern white pine	*Pinus strobus*	S	I	S
American elm	*Ulmus americana*			I
Silver maple	*Acer saccharinum*	I		R
Box elder	*Acer negundo*	S		R
Red cedar	*Juniperus virginiana*	R		R
Virginia creeper	*Parthenocissus quinquefolia*	R		R
Green ash	*Fraxinus pennsylvania*	I		R

[a]PAN = peroxyacetyl nitrate.
[b]S = sensitive, I = intermediate, R = resistant.

Table 5.13. **Calculated annual average air concentrations (in $\mu g/m^3$) of HF and fluorides released from steam plant and processing operations at ORGDP[a]**

Distance (m)	Sector[b]															
	Northwest				Southwest				Southeast				Northeast			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
50																
100						0.10									0.16	0.10
300						0.16					0.10			0.16	0.25	0.14
500					0.10	0.16					0.10			0.14	0.23	0.12
700					0.13	0.17				0.10	0.11			0.13	0.20	0.11
1000					0.11	0.17				0.11	0.10			0.12	0.19	0.10
1500						0.13									0.14	
2000						0.10									0.11	
3000																
4000																

[a]Only concentrations >0.1 $\mu g/m^3$ are listed. Background HF (of 0.2 $\mu g/m^3$) is not included in the data.
[b]Numbered counterclockwise starting at 1 from due north.

ES-4702

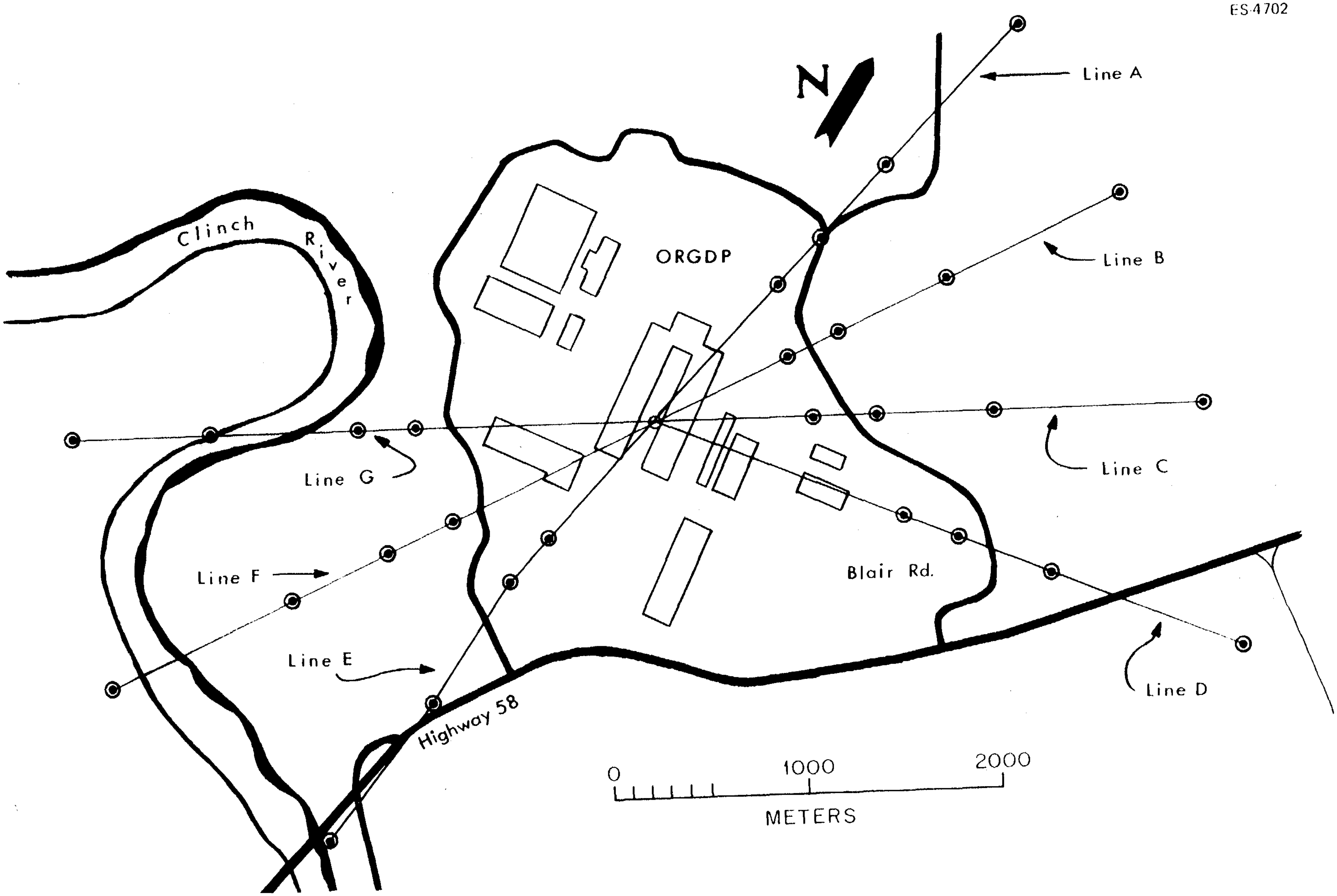

Fig. 5.2. Sampling stations (⊙) for fluorides. The first station is 200 m from the exclusion fence; succeeding stations occur at 500, 1000, and 2000 m.

Fluoride injury in animals is known to occur when fluoride in dietary vegetation reaches 50 ppm or more.[21] The fluorides are deposited in bones and teeth, with lesions there providing the initial symptoms of fluorosis. Only one of the 74 systematically collected vegetation samples contained ≥50 ppm fluoride (transect G, >200 m sample, 57.8 ppm in honeysuckle). None of the 416 small mammals captured showed signs of the fluorosis previously identified in domestic animals. Femur tissue from 65 control individuals, merged into samples of 2 to 34 femurs, averaged 590 ppm fluoride (range 213 to 1346, ±100 ppm). Fluoride concentrations in intermountain western populations of pack rats (*Neotoma*) and rock squirrels (*Spermophilus*) ranged from 100 to 1850 ppm,[22] whereas in deer mice, the average was 135 ppm.[23]

Fluoride concentrations in 16 single-animal samples from ORGDP ranged from 497 to 1647 ppm; in 58 multiple-animal samples, 213 ppm (group of 2) to 2474 ppm (group of 4). High variability characterizes the data, with anomalously high and low values occurring at all points along the gradient of fluoride concentration in vegetation.[24] Yet, when samples on all transects are combined to form average values along the fluoride gradient, a direct relationship to the gradient is apparent. Fluoride concentrations in animals nearest the fluoride source averaged 1097 ppm (∿200 m); at greater distance, fluoride concentrations declined (903 ppm at ∿500). The averaged fluoride values were not significantly different from control values (590 ppm) at ∿1000 m and ∿2000 m (613 and 717 ppm respectively).

The most important results of these studies include (1) the lack of fluorosis symptoms in the 416 animals examined and (2) the measured values of the fluoride content of vegetation, which were below known injury thresholds in domestic animals. The staff, therefore, concludes that fluoride injury to small mammals is unlikely to occur as a consequence of ORGDP operations. It is unlikely that fluoride concentrations would be enhanced in the primary predators of the small mammals (fox, weasel, mink) and in predators further up the food chain [bobcat, mountain lion (Sects. 4.6.1.2 and 4.6.3.1)] that subsisted primarily on animals from the ORGDP area because fluorides are deposited in bones and teeth, which are not consumed in significant quantities.

Oxides of nitrogen. Leaf damage to sensitive plants (Table 5.12) has been induced by NO_2 concentrations of 4700 μg/m³ for 2 hr.[25] The chronic NO_2 concentration at which visible injury occurs on leaves of sensitive plants is 940 μg/m³.[25] Maximum annual NO_x dosages which occur SW of ORGDP (Table 5.14) are only 1.2% of those required to produce visible damage to sensitive plants (Table 5.12). No area within or beyond the reservation will receive annual average NO_x concentrations greater than the 100 μg/m³ used as the national air quality standard (Table 4.17). The staff therefore concludes that NO_x from ORGDP operation are not likely to affect vegetation.

Table 5.14. Calculated annual average air concentrations (in μg/m³) of NO_x released from steam plant and processing operations at ORGDP[a]

Distance (m)	Sector[b]															
	Northwest				Southwest				Southeast				Northeast			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
50																
100	1.3				1.7	2.5	1.5			1.0		1.4		2.4	3.6	2.6
300	4.1	2.7	2.8	3.5	5.3	8.4	4.5	2.3		3.5	3.7	5.0	3.6	8.6	13.4	8.3
500	3.3	2.0	2.4	3.3	4.3	7.0	3.5	2.2		3.6	4.2	4.4	3.1	6.7	10.3	5.9
700	3.2	1.9	2.8	4.1	5.0	8.3	4.0	2.8	1.5	4.9	5.3	5.0	3.2	6.8	10.7	5.8
1000	3.4	2.1	3.5	5.5	6.6	9.9	4.8	3.5	2.0	6.3	6.1	5.5	3.4	7.5	11.4	6.2
1500	2.7	1.8	3.1	4.9	5.9	8.6	4.3	3.1	1.8	5.4	5.1	4.5	2.7	6.2	9.5	5.1
2000	2.1	1.4	2.5	4.0	4.8	6.9	3.5	2.5	1.6	4.4	4.0	3.6	2.2	5.0	7.6	4.2
3000	1.3		1.6	2.7	3.2	4.6	2.4	1.7	1.1	2.9	2.5	2.2	1.4	3.3	5.0	2.8
4000				1.7	2.1	3.1	1.6	1.1		1.9	1.7	1.5		2.2	3.4	1.9

[a] Only concentrations >1 μg/m³ are listed. The maximum concentration at the boundary is 3.1 μg/m³. No concentration exceeds the national standard of 100 μg/m³.

[b] Numbered counterclockwise starting at 1 from due north.

Oxides of sulfur. The effects of SO_2 on vegetation is the subject of more research than is any other air pollutant.[26-37] The research has indicated that the chronic SO_2 concentration at which visible injury can occur is 262 $\mu g/m^3$ (0.1 ppm). Minor effects have been measured at SO_2 concentrations as low as 130 $\mu g/m^3$ (0.05 ppm).[38] Annual SO_2 concentrations at ORGDP average 35 $\mu g/m^3$ (Table 5.25), which is 27% of levels required for visible effects and 13% of levels required to induce injury to plant leaf tissue.

Short-term (4-hr) episodes of high SO_2 concentrations are not likely to exceed threshold values for vegetation damage (Table 5.25). No damage to vegetation that could be ascribed to SO_2 was observed during the multiple field studies at ORGDP.

Fluorocarbons

Freon consists of chlorocarbons and fluorocarbons. Dissociation products of a fluorocarbon compound (trifluorotrichlorethane) have been implicated in the destruction of stratospheric ozone supplies. The stratospheric ozone layer absorbs incoming ultraviolet radiation, and its partial destruction constitutes a possible global problem. Local atmospheric emissions are insignificant with respect to the ozone destruction problem. Freon is not toxic to plants or animals, so its emission from ORGDP will not affect organisms there.

Cooling-tower-drift salts. The emission of circulating-water droplets from cooling towers and their deposition as "drift salts" is discussed in Sect. 5.3.1. Drift-salt deposition values known to cause visible injury to sensitive plants range from 20 kg/ha per year (18 lb/acre per year) above ambient values for tobacco[39] to 95 kg/ha per year (86 lb/acre per year) for soybeans and corn.[40] The reservation boundary annual deposition value [14 kg/ha (12 lb/acre)] is considerably lower than that required to damage tobacco (Sect. 5.3.1). Deposition values within the plant boundary are considerably more than the damage threshold values, even for corn and soybeans, so a certain amount of vegetation damage can be expected there.

The chemical content of drift salts can also be of importance, but at ORGDP it apparently is not. Chromium and zinc from the corrosion inhibitors and scale retardants used at ORGDP occur in drift. Field studies of the chromium and zinc content of soils and plants[41] revealed that chromium was taken up by plants on the reservation. After an equilibrium level of chromium was established in plant tissue, additional increments of airborne or soil-borne chromium had no effects on plants. Background levels of chromium content of plants occurred at 1000 m from cooling towers. Zinc values in plants and soils indicated much less uptake of zinc than of chromium. Zinc concentrations in plant tissue were indistinguishable from background values beyond 200 m from cooling towers. Neither chromium nor zinc produced identifiable damage to plants at ORGDP.

In summary, possible effects of ORGDP atmospheric emissions on the reservation consists of chronic plant injury due to normal emission of cooling-tower-drift salts. Elevated values of fluoride, chromium, and zinc concentrations have occurred in reservation plants, and elevated values of fluoride concentrations have occurred in reservation animals. All elevated concentrations (except fluorides in plants) occurred without apparent injury to the plant and animal species observed.

Concentration of fluorine, zinc, chromium, and technetium-99 in successive links of animal food chains is unlikely. Taylor found that chromium from the ORGDP cooling-tower-drift salts was not retained by primary consumer organisms.[42] Van Hook points out that zinc is diluted, rather than accumulated, from one link to the next in terrestrial food chains.[43] Fluoride was concentrated in the bones and teeth of herbivorous animals studied;[21] thus, it is unavailable for further accumulation in predators. Technetium-99 can be assessed by using the conservative estimates of accumulated dose to man given in Sect. 5.1.2. From these estimates (Table 5.4), it is apparent that the small vertebrates and invertebrates in terrestrial food chains are unlikely to suffer any damage from technetium-99.

5.2.2 Aquatic

Entrainment impacts. Entrainment impacts induced by the operation of ORGDP are not likely to be severe. Under the current withdrawal regime (16 Mgd; 25 cfs; 700 liters/sec), only 0.5% of the average flow of the Clinch River is entrained; in 1984, this will increase to about 0.8%. Under the minimum average monthly flow of about 1000 cfs (2.83×10^4 liters/sec) (10-year record),[44] the withdrawals currently are 2.5% of the flow; the 1984 value will be 3.7%. Since peak ichthyoplankton densities occur in the late spring,[45] when river flows are generally high, it is unlikely that these latter values will ever be reached during the time when the ichthyoplankton community is most vulnerable. Moreover, the data of Loar et al.[45] suggest that (1) tributary streams have much greater densities of ichthyoplankton than the Clinch River itself and that most entrainable larvae remain in the tributaries and (2) ichthyoplankton in the river below Poplar Creek in the vicinity of the intake are largely homogeneously distributed, thus lessening the probability that any high concentrations of larvae ever exist near the intake.

Impingement impacts. The water velocity at the trash racks of the intake is currently about 0.1 fps. At this velocity, little debris collects on the traveling screens, and the screens are therefore only run sporadically. No record of impinged fish exists.[46] In the 1984 operating mode, the approach velocity will increase to about 0.2 fps. Although a few fish may be impinged under these conditions, losses are not expected to be severe. In several cases, approach velocities of ≤0.5 fps have been found adequate to avert substantial impingement losses.[47,48] Moreover, the swimming speeds of the nonentrainable fish found in the area are likely to be greater than the approach velocity, even in the winter.[49-51]

Thermal impacts. Because of the small volume of water affected by thermal discharges (Sect. 5.3.4), it is not likely that any significant aquatic ecological impacts will occur from the operation of ORGDP. Highly localized impacts that may occur include (1) phytoplankton community composition changes, (2) inhibition or stimulation of photosynthesis (depending on the season and the algal species present) and enhancement of respiration/decomposition, (3) attraction of fish during the colder months, and (4) cold shock of fish during power cutbacks. None of these potential effects is likely to be discernible outside a small area since the largest discharge (cooling tower blowdown) only creates a detectable plume that is a maximum of 60 x 40 x 3 ft (18 x 12 x 0.9 m). Moveover, the ΔT at the discharge point is only 1.7° to 3.3°C (3° to 6°F) (Sect. 5.3.4). In comparison with those of most power-generating facilities, this is a low discharge ΔT, and the plume that is produced is much smaller than that produced by most power plants.[52]

No significant change in the characteristics of the thermal discharges is anticipated for 1984 operation of the facility (Sect. 5.3.3).

Impacts of chemical discharges. Although ORGDP operation has had, and continues to have, a significant effect on the chemical loading of Poplar Creek and the Clinch River, much (if not most) of the serious contamination of these water bodies appears to be derived from upstream sources. The Poplar Creek Watershed receives effluent from coal mining areas, sewage treatment facilities, and the Y-12 Plant. The latter, in particular, is suspected of producing most of the stream burden of mercury near the ORGDP site.

Potential eutrophication impacts induced by the sewage effluents and nitrate discharges in the process wastewater are discussed in Sect. 5.3.3.

As indicated in Sect. 5.3.3, some of the constituents in the effluents are at concentrations that would be toxic to biota if the waste streams were undiluted,[53,54] as might be found in localized areas during periods of zero flow (Table 5.15). Some of these substances occur at concentrations several orders of magnitude greater than the criterion for protection of aquatic biota (e.g., nickel, zinc, and residual chlorine). Thus, significant degradation of the biotic communities could be expected in portions of Poplar Creek and the Clinch River during this worst-case situation. Possible effects include (1) acute and/or chronic toxic effects induced by the parameters listed in Table 5.15, except for dissolved solids and sulfates, (2) community composition changes (especially in phytoplankton, periphyton, and zooplankton) caused by osmotic shifts from the dissolved solids and sulfate additions; and (3) increased bioaccumulation of heavy metals.

Two proprietary chemicals in the effluent at ORGDP discharge location 1 (Betz Polynodic 562 and Betz 35A; Table 2.8) are of unknown toxicity. These chemicals are essentially polyphosphonates, which are thought to be readily degraded. Because the blowdown becomes greatly diluted, the levels of these compounds would not be expected to become significant except in the immediate discharge area.

The frequency of occurrence of zero flows at the ORGDP site is unknown, as is the size of each plume that would be produced by each discharge under no-flow conditions. Thus, it is not possible to quantify the impacts that would occur. Under average flow conditions (Poplar

Table 5.15. Effluent concentrations (1978 operation) at ORGDP discharge locations

Parameter	Protection criterion[a] (mg/liter)	Maximum monthly discharge concentration[b] (mg/liter) Discharge location No.[c] 1	2	3	4	5	6	7	8
Ammonia[d]	0.02[e]				0.51				
Cadmium	4×10^{-4} [f]						0.005		
Chlorine (total residual)	0.002				2.0	2.0			
Copper	~0.020[g]		0.50	0.50			0.12		
Cyanide	0.005	0.007		0.006			0.007		
Dissolved solids	h	900	4000	820					
Lead	~0.050[g]		0.07						
Manganese	1.5[i]		2.6						
Mercury	5×10^{-5}	0.004	0.004				0.002		
Nickel	0.005[g]	1.86	2.5	0.800			0.15		
Sulfate	h	500	1200	610			2100		320
Zinc	1×10^{-4}	1.2		0.10			0.50		

[a] U.S. Environmental Protection Agency, *Quality Criteria for Water*, EPA-440/9-76-023, 1976.
[b] Value given only if in excess of protection limit.
[c] Discharge locations are shown in Fig. 2.1.
[d] Unionized NH_3 concentration at maximum reported pH.
[e] In the unionized form.
[f] For sensitive organisms (e.g., cladocerans) in soft water.
[g] Based on 0.1 × 96-hr LC_{50}, using a sensitive aquatic species.
[h] A concentration that does not induce changes in community composition.
[i] Minimum tolerance value for a sensitive organism.

Creek, 200 cfs; Clinch River, 4800 cfs) all the parameters would be reduced (outside the mixing zones) to levels unlikely to harm the biota, with the exception of mercury, zinc, and nickel. These metals occur at sufficiently high average and maximum background concentrations (Tables 2.8 through 2.12 and Table 4.7) to potentially induce toxic effects without the ORGDP additions. Mercury, in particular, has been found at highly elevated levels upstream in Poplar Creek (up to 2 μg/liter). Thus, additions from ORGDP will potentially exacerbate any toxic effects that may already be occurring.

Analyses of sediment and fish tissue are potentially useful indicators of the long-term degradation occurring in an environment from heavy-metal inputs. Sediment analyses conducted in the area are reported in Sect. 4.4.1.4. Interpretation of the results of these analyses is somewhat difficult because (1) the precision of many of the tests is low, especially at lower concentrations;[55] (2) sediment texture and organic content can greatly affect metal absorption and retention;[56] and (3) downstream migration of the metals ordinarily occurs with time, complicating a determination of contaminant sources. Furthermore, sediment Eh and pH, which can be quite variable within a given habitat,[57] affect metal retention.[58] Despite these facts, all the heavy metals examined (cadmium, copper, lead, manganese, mercury, nickel, and zinc) appear to be elevated in the vicinity of ORGDP, with the possible exception of cadmium (Sect. 4.4.1.3). Mercury concentrations are substantially greater than those expected in pristine areas (see discussion in Sect. 4.4.1.3). The extent to which ORGDP discharges contribute to the sediment metal burden is as yet unknown. An examination of Table 4.9 indicates that sediment values are high upstream of the facility (station 19; mouth of the East Fork of Poplar Creek).

The results of a 1977 study of trace substances in fish tissues in the vicinity of ORGDP are discussed in detail in ref. 45. In this analysis of 362 fish (including 15 species), only mercury and polychlorinated biphenyls (PCBs) were found at levels indicating contamination (Tables 5.17 through 5.22). Table 5.16 lists selected mean concentrations of trace elements in fish (in relatively uncontaminated areas, as determined by various investigators), and Tables 5.17 through 5.22 give data on the tissue concentrations found at various stations in the Clinch River and Poplar Creek. Generally, migratory species that enter Poplar Creek to spawn had the

Table 5.16. Trace element concentrations in fish — from selected studies

Element	Concentration (μg/g)				
	Lake Erie	Great Smoky Mountains National Park	Great Lakes (Michigan, Superior, and Erie)	Lake Cayuga, N.Y.	Wintergreen Lake, Ill.
Mercury	0.522	0.036			0.18
Lead				0.011	0.329
Cadmium	0.055		0.09	0.04	0.037
Zinc	14.2		1.3	0.21	
Copper	1.08			0.02	
Chromium	0.23		1.0	0.016	
Nickel				0.014	

Source: James M. Loar et al. *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Table 5.17. Mean concentrations of metals and PCBs in fish collected from station PCM 11.0, spring 1977

	Concentration (μg/g wet weight)							
	Hg	Pb	Cd	Zn	Cu	Cr	Ni	PCBs
White bass	0.17 ± 0.008	0.21 ± 0.02	0.008 ± 0.001	5.0 ± 0.5	0.6 ± 0.06	0.09 ± 0.02	0.5 ± 0.04	0.4 ± 0.06
Gizzard shad	0.04 ± 0.002	0.13 ± 0.02	0.007 ± 0.001	4.0 ± 0.3	0.8 ± 0.1	0.16 ± 0.07	0.6 ± 0.1	0.3 ± 0.05
Bluegill	0.10 ± 0.03	0.09	0.023 ± 0.004	8.0 ± 1.4	0.5 ± 0.1	0.29 ± 0.11	0.6 ± 0.2	0.3

Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

lowest tissue levels (e.g., gizzard shad and white bass), and resident bottom feeders and top carnivores in the creek had the highest levels. More than 14% of the game fish from Poplar Creek and the Clinch River had muscle tissue mercury concentrations in excess of 0.5 μg/g, whereas 2% of the game fish from all six sites had mercury levels exceeding 1.0 μg/g, the action level on mercury in fish recently recommended by the U.S. Food and Drug Administration (FDA). A largemouth bass from station PCM 5.5 had the highest mercury concentration (2.14 μg/g wet weight) of all the fish collected.

Significant seasonal differences ($p < 0.05$) in tissue concentrations of mercury were found in largemouth bass and *Lepomis* sp. (probably bluegill). Thus, either different populations of fish of these species were sampled, or the same populations were exposed to greater levels of mercury during the season when the highest tissue levels occurred. Differences in available mercury could have resulted from increases in effluent releases into the water column, or additional mercury may have been mobilized from the sediments.[59]

The data indicate that many of the fish have tissue mercury concentrations that exceed a recognized FDA criterion, above which human consumption is not recommended. However, a previous study[60] suggests that the mercury that is contaminating fish comes primarily from sources upstream of ORGDP (in the East Fork of Poplar Creek and in Bear Creek).

Table 5.18. Mean concentrations of metals and PCBs in fish collected from station PCM 5.5, 1977

	Concentration (μg/g wet weight)														
	Hg		Pb		Cd		Zn		Cu		Cr		Ni		PCBs
	1[a]	2[b]	1	2	1	2	1	2	1	2	1	2	1	2	1
White bass	0.19 ± 0.03		0.06 ± 0.01		0.008 ± 0.0005		4.0 ± 0.4		0.5 ± 0.04		0.05 ± 0.01		2.0 ± 0.5		1.0 ± 0.2
Gizzard shad	0.04 ± 0.003		0.10 ± 0.01		0.008 ± 0.0004		4.0 ± 0.2		0.7 ± 0.04		0.07 ± 0.02		0.7 ± 0.07		0.7
Bluegill	0.19 ± 0.06				0.028 ± 0.002		7.0 ± 1.8		0.36 ± 0.04				1.0		
Lepomis sp.	0.29 ± 0.06	0.43 ± 0.10	0.13 ± 0.03	0.10 ± 0.03	0.022 ± 0.007	0.013 ± 0.002	8.0 ± 1.2	6.0 ± 0.5	0.2 0.04	0.3 ± 0.02		0.02	0.9 ± 0.08	0.6 ± 0.02	0.2

[a]1 = fish collected in the spring.
[b]2 = fish collected in the fall.
Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Table 5.19. Mean concentrations of metals and PCBs in fish collected from station PCM 0.5, 1977

	Concentration (µg/g wet weight)																					
	Hg			Pb			Cd			Zn			Cu			Cr			Ni		PCBs	
	1[a]	2[b]	3[c]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	1	3
White bass	0.15 ± 0.02	0.24	0.16 ± 0.07	0.10 ± 0.02	0.13	0.12	0.011 ± 0.002	0.008	0.009 ± 0.002	5.0 ± 0.5	9.0	5.0 ± 0.7	0.7 ± 0.06	0.4	0.5 ± 0.2	0.11 ± 0.03		0.06	1.8 ± 0.3	0.9	2.0 ± 0.8	0.2
Gizzard shad	0.05 ± 0.008			0.08 ± 0.009			0.008 ± 0.001			4.0 ± 0.5			1.0 ± 0.1			0.05 ± 0.01			2.5 ± 0.2		0.4 ± 0.05	
Bluegill	0.19 ± 0.03			0.07 ± 0.01			0.025 ± 0.005			10.0 ± 1.5			0.37 ± 0.04			0.15 ± 0.08			0.8 ± 0.09		0.4 ± 0.08	
Lepomis sp.			0.62 ± 0.07			0.12 ± 0.01			0.013 ± 0.001			8.0 ± 0.6			0.11 ± 0.01			0.05 ± 0.02				
White crappie	0.07 ± 0.01						0.008 ± 0.001			6.0 ± 0.4			0.26 ± 0.02			0.04 ± 0.01					0.5 ± 0.2	
Channel catfish	0.24 ± 0.04			0.13 ± 0.02			0.007 ± 0.001			5.0 ± 0.7			0.7 ± 0.1			0.36 ± 0.18			1.9 ± 0.7		2.3 ± 0.9	
Largemouth bass	0.20 ± 0.04		0.71 ± 0.09			0.13	0.017 ± 0.003		0.013	9.0 ± 1.6		5.0	0.5 ± 0.08		0.3	0.23 ± 0.13					0.4 ± 0.1	0.3
Longnose gar	0.66 ± 0.15			0.33 ± 0.12			0.048 ± 0.016			7.0 ± 1.3			0.6 ± 0.1			0.28 ± 0.11			0.5		3.2 ± 1.8	

[a] 1 = fish collected in April.
[b] 2 = fish collected in May.
[c] 3 = fish collected in October and November.
Source: James M. Loar et al., *Environmental Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM 6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Table 5.20. Mean concentration of metals and PCBs in fish collected from station CRM 15.0, 1977

	Concentration (μg/g wet weight)												
	Hg		Pb		Cd		Zn		Cu		Cr	Ni	PCBs
	1[a]	2[b]	1	2	1	2	1	2	1	2	1	2	1
White bass		0.04 ± 0.005		0.12 ± 0.01		0.016 ± 0.003		8.0 ± 0.5		0.3 ± 0.10			
Gizzard shad	0.07 ± 0.01		0.05 ± 0.002		0.008 ± 0.001		2.0 ± 0.1		0.6 ± 0.1		0.36 ± 0.08		0.5 ± 0.2
Lepomis sp.		0.53 ± 0.11		0.08 ± 0.006		0.009 ± 0.001		12.0 ± 0.4		0.3 ± 0.01		0.6 ± 0.03	
Largemouth bass		0.21 ± 0.05		0.19 ± 0.03		0.026 ± 0.004		6.0 ± 0.4		0.1			

[a]1 = fish collected in the spring.

[b]2 = fish collected in the fall.

Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Table 5.21. Mean concentration of metals and PCBs in fish collected from station CRM 11.5, 1977

	Concentration (μg/g wet weight)							
	Hg	Pb	Cd	Zn	Cu	Cr	Ni	PCBs
Gizzard shad	0.10 ± 0.01	0.32 ± 0.05	0.020 ± 0.006	9.0 ± 1.5	0.8 ± 0.4	0.04 ± 0.003		
Shad	0.05 ± 0.005	0.10 ± 0.01	0.014 ± 0.008	4.0 ± 0.4	0.6 ± 0.05	0.10 ± 0.03	0.7 ± 0.2	0.4 ± 0.06
Lepomis sp.	0.49 ± 0.14	0.30 ± 0.02	0.014 ± 0.001	11.0 ± 1.4	0.4 ± 0.03	0.04 ± 0.005		

Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant*, ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

Tissue concentrations of PCBs in the fish were also determined because elevated sediment values were found (Sect. 4.4.1.4). Most of the fish analyzed had concentrations below the FDA action level of 5 μg/g. However, concentrations near this level were found in the ten channel catfish collected in Poplar Creek. Two fish had levels as high as 6.0 and 7.0 μg/g, but the highest body burden — 8.5 μg/g — was found in a longnose gar from the creek.

The source of PCB contamination is unknown. No PCBs of the same chemical composition as those found in the area have been used by ORGDP in recent years; data are lacking on what compounds may have been discharged before this time.[61] Although sediment levels are lower upstream of the facility, downstream migration of the compounds from an upstream source is highly possible.

The physical and chemical milieus of the waters near ORGDP (especially Poplar Creek) suggest that the biotic communities within them are under stress. The stressors are many and varied — turbidity, allochthonous sediment (especially coal fines), heavy metals and other toxicants, degradable organic matter, excessive nitrogen and phosphorus, altered flow regimes, altered water temperatures. Despite this, functioning communities exist and, in some cases, thrive. Thus, a phytoplankton, zooplankton, and periphyton assemblage fairly typical of North American rivers exists (Sect. 4.6.2), and Poplar Creek apparently serves as a major spawning and nursery

Table 5.22. Mean concentration of metals and PCBs in fish collected from station CRM 10.5, 1977

	Concentration (µg/g wet weight)													
	Hg		Pb		Cd		Zn		Cu		Cr		Ni	PCBs
	1[a]	2[b]	1	2	1	2	1	2	1	2	1	2	2	1
White bass		0.06 ± 0.004		0.14 ± 0.02		0.014 ± 0.002		4.0 ± 0.4		0.5 ± 0.04		0.07 ± 0.02		
Gizzard shad	0.04 ± 0.002		0.10 ± 0.01		0.007 ± 0.001		4.0 ± 0.4		0.7 ± 0.04		0.16 ± 0.06			0.2 ± 0.04
Lepomis sp.	0.17	0.16 ± 0.03	0.29	0.09	0.008	0.008	10.0	10.0	0.3	0.4			0.8	
Bluegill	0.23		0.27		0.007		13.0		0.3					
Largemouth bass	0.08 ± 0.04	0.32 ± 0.07		0.07 ± 0.01	0.006 ± 0.0005	0.017 ± 0.002	10.0 ± 1.3	3.0 ± 0.4	0.5 ± 0.1	0.5 ± 0.07		0.10 ± 0.03		0.4
Striped bass		0.08 ± 0.022		0.20 ± 0.038		0.007 ± 0.002		6.0 ± 0.2		0.4 ± 0.02		0.05	0.6 ± 0.06	
Sauger		0.48 ± 0.09		0.11 ± 0.02		0.014 ± 0.007		4.0 ± 1.0		0.3 ± 0.09		0.05 ± 0.03		

[a] 1 = fish collected in the spring.
[b] 2 = fish collected in the fall.
Source: James M. Loar et al., *Environmental Analysis Report for the Oak Ridge Gaseous Diffusion Plant,* ORNL/TM 6714, Oak Ridge National Laboratory, Oak Ridge, Tenn. (in preparation).

ground for fish. However, some changes in community and ecosystem structure and function undoubtedly have occurred as a result of these anthropogenic disturbances. Moreover, stressed systems are highly susceptible to the effects of additional perturbations. It is therefore advantageous to curb, where possible, the input of existing or additional factors that may affect the biota of Poplar Creek and the Clinch River. Moreover, the potential health effects resulting from the consumption of mercury- and PCB-laden fish caught in the area dictates careful monitoring of contaminant levels. Also, upstream sources of mercury and PCBs need to be determined and evaluated, with the aim of reducing their effects. An assessment of Y-12 operations (in preparation) will give additional information on upstream sources.

Radiation dose to aquatic biota. Doses to aquatic plants, to invertebrates, and to fish and waterfowl that live in the receiving water bodies below effluent discharge regions have been calculated. These doses are due to water intake and ingestion by organisms living in water bodies that receive the liquid effluent. The discharge-region concentrations were calculated from average annual radionuclide releases and from average annual flows for the receiving water bodies (see Table 5.9).

All dose calculations were based on the assumption that the radionuclide concentrations in water remain constant and that the biota reach a steady-state concentration where the input of radioactive material to the environment is constant. The organisms are assumed to spend all year in Poplar Creek water that has the maximum concentration of discharged radionuclides. All calculations were completed by use of adaptions of standard models and procedures for estimations of radiation dose (see ref. 6). However, the doses are probably conservative, since it is highly unlikely that any of the mobile life forms spend a significant portion of their life span at the site of maximum concentration of radioactivity.

Tables 5.23 and 5.24 list the radiation doses calculated for organisms living in or near the discharge of liquid effluents from ORGDP into Poplar Creek. Aquatic plants and invertebrates are estimated to receive the highest internal doses, which are mainly attributable to uranium-234.

Table 5.23. Estimated annual internal dose resulting from liquid effluents to biota that live in Poplar Creek at the ORGDP boundary

Radionuclide	Concentration (μCi/ml)	Dose (millirads)			
		Algae	Invertebrates	Fish	Waterfowl or muskrats
Tc-99	1.5E−8[a]	1.0	1.3E−1	3.9E−1	7.6E−2
U-234	9.6E−10	8.8E2	8.8E1	8.8	1.2
U-235	4.6E−11	3.9E1	3.9	3.9E−1	5.5E−2
U-236	1.5E−11	1.3E1	1.3	1.3E−1	1.8E−2
U-238	6.6E−10	5.3E2	5.3E1	5.3	7.4E−1
		1.5E3	1.5E2	1.5E1	2.1

[a] Read as 1.5×10^{-8}.

The significance of these estimated radiation doses to biota other than man is not immediately known. The literature on radiation effects on organisms is extensive, but very few studies have been conducted to determine the effects of continuous low-level exposure to radiation from ingested radionuclides on natural aquatic or terrestrial populations. The most recent pertinent studies point out that, whereas the existence of extremely radiosensitive biota is possible and increased radiosensitivity in organisms may result from environmental interactions, no biota have yet been discovered that show more sensitivity to radiation exposure than those found in the area surrounding ORGDP. The BEIR report states, in summary, that evidence to date indicates that no other living organisms are very much more radiosensitive than man.[62]

Table 5.24. Estimated annual external dose resulting from liquid effluents to biota that live in Poplar Creek at the ORGDP boundary

Radionuclide	Dose to all biota (millirad)	
	Beta plus gamma	Gamma
Tc-99	1.3E−2[a]	0.0
U-234	9.6E−10	9.6E−10
U-235	4.6E−11	4.6E−11
U-236	1.5E−11	1.5E−11
U-238	5.6E−10	5.6E−10
	1.3E−2	1.6E−9

[a] Read as 1.3×10^{-2}.

The present (and projected) operation of ORGDP contributes to the chemical loading of Poplar Creek and the Clinch River. During periods of low or zero flow, the quantities released may induce severe local impacts (toxicity, eutrophication), but the effects from such episodes should be transient, with the possible exception of increased heavy-metal body burdens. During periods of average flow, significant impacts from the effluents above are not likely, but toxicant additions may incrementally affect organisms exposed to high ambient toxicant levels. The currently high mercury and PCB body burdens in fish and the high sediment concentrations of these and other contaminants likely stem largely from releases unrelated to current ORGDP operation. Past operation has likewise been of dubious significance in affecting these levels.

Thermal, impingement, and entrainment effects appear to be highly localized and of little significance to the overall stream systems. No detectable radiological impact is expected in the aquatic biota or in terrestrial mammals as a result of the quantity of radionuclides released into the aquatic habitats or into the air by ORGDP.

5.3 PHYSICAL ENVIRONMENT

5.3.1 Air quality

Average meteorological conditions. The only gaseous pollutant that exceeds Tennessee ambient air quality standards (Table 4.17) in the vicinity of ORGDP is HF. Levels measured in 1978 in the ORGDP area exceeded the 1.2-$\mu g/m^3$ 30-day average Tennessee standard only two weeks of the year.[63] Uprating and improvement of facilities at ORGDP prior to 1984 will reduce fluoride discharges by about 8% relative to the current level. Therefore, Tennessee ambient air quality standards for HF should be exceeded only infrequently in the vicinity of the plant site in the future. The estimated maximum pollutant concentrations at the plant boundary due to the operation of ORGDP represent 40%, 44%, and 3% of the ambient air quality standards[64,65] for HF, SO_2, and NO_x respectively. HF and SO_2 values primarily represent background concentrations.

Gaseous emissions of SO_2 may be converted to an acid form if the exhaust plume contacts atmospheric moisture. Such moisture can be provided by rain, cooling tower plumes, or high atmospheric humidity. Effects attributed to SO_2 and SO_3 under such conditions[65] include metal corrosion, deterioration of building materials, discoloration of paint, and reduced tensile strength of textiles.[66] Similar effects are expected to occur with HF formations. However, measurable impacts from acid formation should be confined to buildings and materials within the plant buffer zone.

No acreage will receive annual average NO_x concentrations greater than the national air quality standard of 100 $\mu g/m^3$ from ORGDP's output. Generally, routine releases of gaseous effluents from the gas centrifuge test facilities should have only a slight incremental impact on regional air quality or land use. No acreage outside the plant boundary will receive combined dosages higher than the national or state standards.

<u>Stable, short-term meteorological conditions</u>. Potential impacts during severe but short-term meteorological conditions must be considered. To consider dispersion for all variations of unusual meteorology is impractical; therefore, atmospheric concentrations of SO_2, HF, and NO_x were calculated for a severe condition defined strictly by Pasquill type F stability and a 2.3-mph (1.0-m/sec) wind. The severe condition, however, does not fully represent possibly poorer circumstances of dispersion related to air entrapment by short-term inversions, fumigation (type G stability), or persistent stagnation. Graphs for estimating atmospheric dispersion were used to determine χ/Q values for the severe condition.[67] The χ/Q values at various distances were used to calculate the air concentrations of SO_2 and HF (Table 5.25). Data in Table 5.25 indicate that HF and SO_2 concentrations are well below those that damage plants (4-hr dose level). The oxides of nitrogen, which provide a basic nutrient to plants, rarely cause damage.

Table 5.25. Calculated gaseous pollutant concentrations (in $\mu g/m^3$) for severe meteorological conditions[a] not expected to persist for more than 4 hr per episode

Distance (m)	χ/Q		SO_2			HF		
	51-m stack height steam plant	Other processes with a 20-m stack height	Steam plant	Other processes	Total	Steam plant	Other processes	Total
1,000	2.9E−8	1.1E−5	2.92	4.6E−2	3.0	4.4E−3	3.3E−1	3.3E−1
2,000	1.4E−6	1.4E−5	143.0	5.6E−2	143.1	2.2E−1	4.0E−1	6.2E−1
3,000	2.9E−6	8.0E−6	289.0	3.3E−2	289.0	4.3E−1	2.3E−1	6.6E−1
4,000	2.6E−6	4.3E−6	261.0	1.8E−2	261.0	3.9E−1	1.3E−1	5.2E−1
5,000	2.2E−6	2.5E−6	223.0	1.0E−2	223.0	3.4E−1	7.2E−2	4.1E−1
10,000	7.2E−7	2.2E−6	72.3	9.2E−4	72.3	1.1E−1	6.5E−3	1.2E−1
20,000	6.4E−8	5.0E−9	6.43	2.1E−5	6.43	9.6E−3	1.5E−4	9.8E−3
Minimum background concentration					35			0.2
24-hr national or state standard					365			2.9
Dosage levels at which damage to vegetation occurs								
1 hr					2486			200
2 hr					1308			100
4 hr					916			20
24 hr					262			1.5
Lowest level					262			0.2

[a]Pasquill type F stability at a 2.2-mph (1.0-m/sec) wind speed. Concentrations are centerline values.

<u>Cooling tower drift</u>. The mechanical-draft cooling tower is a major potential source of impacts on air quality because of its heat dissipation system. Ground-level plume contact (fogging), drift deposition, cold weather icing, and noise are the impacts associated with operation of mechanical-draft cooling towers.

For evaporative cooling systems such as mechanical-draft cooling towers, the primary atmospheric effects are associated with discharge of water vapor and the formation of a visible (water droplet) plume due to the condensation of water vapor as it mixes with cooler ambient air. About 10% of the time, cooling tower plumes initiate cloud development. Typical plume length under most meteorological conditions at ORGDP was observed to be about 100 to 200 m, with a rise of 100 to 200 m. The maximum plume length observed was 600 m.[63]

Within affected areas, ground-level fogging can occur with a potential for interference with traffic. Conditions conducive to fog formation in the plume also generally result in natural fog formation. Thus, tower-produced fog may be viewed as an increment of the naturally occurring phenomenon and may, at times, be indistinguishable from the fog normally present. The occurrence of fogging along State Highway 58 adjacent to ORGDP is estimated to be increased by about 16% over natural fog occurrence by the drift from the cooling towers in 1984 (Sect. 2.2.3.3). The impacts of fogging on air quality will be minor except within a relatively limited radius of ORGDP.

A potential exists for interaction of cooling-tower vapor plumes with steam-plant stack effluents and other process effluents. However, distant placement of cooling towers from steam plant and process buildings provides separation of the plumes. In addition, cooling tower plumes tend not to rise as high as others; therefore, plume interactions are highly improbable.

When ambient temperatures are sufficiently low, cooling tower plumes can cause icing on surrounding structures, surface terrain, and vegetation. This icing potential does exist on 60 to 70 days (300 to 350 hr) per year, during the five-month period of November through March when natural fogs are common.

Carry-over of circulating water droplets (i.e., cooling tower drift) and the subsequent deposition of chemicals contained in them may pose some potential for detrimental effects on air quality. Air concentrations of drift measured 100 m downwind from the K-31 cooling tower were 0.0010 $\mu g/m^3$ for chromium, 0.7 $\mu g/m^3$ for calcium, and 0.1 $\mu g/m^3$ for magnesium. The drift model (ORFAD) used by the staff predicts a maximum annual salt deposition rate of 1500 lb/acre to the southwest. At a distance of 3000 m (the plant boundary), this is reduced to about 12 lb/acre per year. The staff calculated that rainfall annually deposits about 44 lb of salts per acre. Thus, outside the plant boundary, the maximum salt deposition from cooling tower drift is expected to be less than normal deposition from rainfall. However, within the plant boundary, as much as 500 acres may receive salt deposition in excess of that expected from rainfall.

5.3.2 Land use

Biocidal discharges. Herbicides are used to control noxious plant species in the vicinity of ORGDP buildings. About 4000 lb per year of Unibar 31 is applied at a rate of 1 oz/ft^2 to control vegetation near electric switchyards, fireplugs, railroad tracks, and security fences. Paraquat CL is sprayed at 1 qt/acre to suppress weeds and grass around trees and shrubs. Similarly, insecticides are used, but to a minimal extent. About 65 gal of Raid is used annually for this purpose. These biocides are used in accordance with accepted practices to control their impact on terrestrial biota. Various pesticides have been used at the existing site without detectable effect; therefore, no adverse impacts on land use are anticipated.

Effects of other chemical discharges. Chemicals discharged during the operation of ORGDP that may affect land use involve gaseous effluents from the process buildings, steam plant, and cooling tower and solid wastes and sludges for disposal. Major gaseous effluents from the steam plant and process buildings are detailed in Tables 2.6 and 2.7. Hydrogen fluoride (HF), sulfur dioxide (SO_2), and nitrogen oxides (NO_x) are normally the most important. Particulates are also released, but concentrations will not approach national air quality standards (Table 4.17).

Concentrations of HF, SO_2, and NO_x that occur beyond reservation boundaries (Tables 5.13 and 5.14) are not sufficient (Sects. 5.2.1 and 5.3.1) to damage crops, timber, or to injure domestic animals. Salts from cooling tower drift (Sects. 5.2.1 and 5.3.1) are similarly attenuated at reservation borders; therefore, no adverse impacts from atmospheric discharge of chemicals are anticipated on land uses outside the reservation.

Land requirements for disposal of wastes generated during the operation of ORGDP through the year 2000 include 20 acres for radioactively contaminated wastes and 2 acres for sanitary landfill. Disposal of wastes will occur in areas of the reservation already dedicated to these uses.

5.3.3 Water quality

Thermal effects. Two discharges exist for the disposal of heated effluent (Sect. 2.2.3.3). A small volume [5 gpm (19 liters/min)] of steam condensate at about 38°C (100°F) that enters Poplar Creek at discharge location 3 (Fig. 2.1) results in a virtually undetectable plume (Sect. 2.2.3.3). Therefore, no discernible impacts from this effluent are likely to occur. The cooling tower blowdown is discharged to the K-901-A holding pond and subsequently released to the Clinch River at discharge location 6 (Fig. 2.1). The total flow into the river (which includes additions from springs and runoff) is about 1300 gpm; the effluent temperature ranges from 1.7° to 3.3°C (3° to 6°F) above ambient. Detection of the plume is limited to a maximum area of 60 by 40 ft (18 by 12 m) and a maximum depth of 3 ft (0.9 m) (Sect. 2.2.3.3); the river bottom is not impinged by the warmer water. Because of the small volume of water affected, no impact on water use is likely. The volume of heated water discharged by ORGDP is not expected to increase by 1984. Thus, the above analysis of thermal effects is applicable to operating conditions projected to occur then.

Chemical effects. Considerable improvements in effluent quality have been made at ORGDP in the last several years. Since 1971, the following major changes have occurred: (1) both sewage treatment facilities were upgraded to provide secondary treatment; (2) chromium reduction capabilities were added to treat cooling water blowdown, and chromium was eliminated from the fire-protection-water system; (3) pH and flow adjusters were added to two effluent streams (Nos. 1 and 2), providing pH improvement, suspended solids reduction, and heavy metals reduction (Sect. 2.2.3.3).[68] A few additional wastewater improvements will be made before 1984. These will result in (1) a slight reduction in releases of chromium, copper, and dissolved solids from discharge location 1, (2) a large reduction in NO_3^- releases from the same source, (3) a slight decrease in the concentration of dissolved solids in the effluent at discharge location 2, and (4) a large reduction in the nickel released from location 2 (Tables 2.8 through 2.14). The discharge locations are shown in Fig. 2.1.

Assessing the impact of the liquid effluents is very difficult because of the complex hydrology of Poplar Creek and the Clinch River (Sect. 4.4.1.1). Although no data are available on the frequency of occurrence, periods of essentially zero flow exist in both streams in the vicinity of ORGDP (Sect. 4.4.1.1). Under such conditions, the effluents (Tables 2.8 through 2.14) would enter the streams without much initial dilution. This worst-case situation would result in a plume of unknown size around each discharge, in which several toxicants would be found at levels detrimental to aquatic biota (Sect. 5.2.2). Despite this fact, only some of the parameters in the undiluted plumes would exceed current drinking water standards[54] (e.g., Mn/Hg, NO_3^-, SO_4^{2-}, and dissolved solids at discharge location 1), and minimal dilution (about fourfold) would reduce all concentrations to safe intake values. Since it is unrealistic to envision any water withdrawals for sanitary use (for potable water and related uses) occurring within the plumes, current effluents from ORGDP are not likely to restrict future sanitary water use in the area, with one possible exception. Mercury levels upstream of the facility range up to 2 μg/liter (Table 4.7), which is the maximum concentration allowed in drinking water.[54] Thus, any mercury added by ORGDP constitutes significant incremental loading for Poplar Creek. Poplar Creek likewise apparently significantly affects mercury concentrations in the Clinch River; maximum values upstream in 1977-1978 were below the detection limit (1 μg/liter), whereas maximum values downstream were as high as 3 μg/liter (Table 4.7). During average flow conditions in Poplar Creek (200 cfs), maximum mercury discharges from ORGDP will increase the concentration of the metal in the stream by only about 0.08 μg/liter. However, during a seven-day, ten-year low flow ($7Q_{10}$) of 26 cfs, the increase would be about 0.5 μg/liter.

The effluents from current operational characteristics (based on previous one-year period) meet applicable state and federal standards, with the following exceptions: (1) maximum monthly levels of suspended solids (56 mg/liter) at discharge location 1 exceed the National Pollutant Discharge Elimination System (NPDES) limit of 30 mg/liter (the maximum levels of suspended solids occurred during periods of precipitation and thus are not in violation of the NPDES permit); (2) the Tennessee Department of Health guideline of 1400 mg/liter for SO_4^{2-} is exceeded at discharge location 6 (maximum monthly concentration = 2100 mg/liter); and (3) the NPDES limit of 30 mg/liter for suspended solids is exceeded at the same discharge location by the maximum monthly value of 41 mg/liter. Tables 2.8 through 2.14 list the current NPDES requirements and state guidelines for each effluent stream.

Nitrogen and phosphorus are added to Poplar Creek from the two sewage treatment facilities, but the quantities are generally too small to cause a significant increase above ambient levels. Thus, it is not likely that significant stimulation of nuisance algal growth occurs from these discharges, especially since the phytoplankton and periphyton are probably light-limited most of the year (Sects. 4.6.2.1 and 4.6.2.2). Under average flow conditions, the nutrient additions would be undetectable (using current analytical methods) after thorough mixing of the effluent in the stream. During a $7Q_{10}$ flow of 26 cfs, total nitrogen would be increased by only about 0.04 mg/liter, and total phosphorous would be elevated by only about 0.03 mg/liter. A more significant source of nutrient loading comes from nitrates in the process-water effluents at discharge locations 1, 2, 5, and 6 (Tables 2.8 through 2.11), where the ion occurs at concentrations up to 88 mg/liter. As Table 4.7 indicates, mean nitrate levels are elevated below these discharge points. However, nitrogen is not likely to be a limiting nutrient for algal growth in the vicinity of ORGDP (when not light- or temperature-limited, the algae are probably phosphorus-limited; see Sect. 4.6.2.1). The inputs could induce greater growth downstream where turbidity is lower (e.g., portions of Watts Bar Reservoir) and the phosphorous to nitrogen ratio is such that phosphorus does not limit growth.[69]

The water-use effects of increased eutrophication, if it results in stimulated plant growth, are several.[70] Decaying plants reduce dissolved oxygen levels, which can result in fish kills. Algal communities change, with resultant changes in higher trophic levels, including fish. The waters are generally less pleasing aesthetically, thus curtailing recreation. Blooms of algae can produce substances that taint the taste of water; some of the compounds are also toxic and represent a hazard to the wildlife and livestock that ingest them.[71]

Although nitrates are discharged into Poplar Creek in significant quantities, the total amount is less than that added by a municipal sewage treatment plant (with secondary treatment) serving 15,000 people.[72] Many communities discharge sewage into the Clinch River system, including Oliver Springs (population ~3000) and Oak Ridge (population ~30,000). Thus, nitrogen loading by ORGDP does not represent the major source of the nutrient to the river system. Moreover, it is likely that only a small portion of the area's waters are nitrogen-limited.[73] Thus, little plant growth stimulation is probable in the Clinch River system as a result of the nitrate inputs from ORGDP.

5.3.4 Water use

About 16 Mgd [25 cfs (700 liters/sec)] of water is withdrawn from the Clinch River by ORGDP; this is projected to increase to 24 Mgd [37 cfs (1050 liters/sec)] by 1984 (Sect. 2.2.3.3). About 25% of the water is returned to the river (in the form of blowdown, treated sewage, etc.). Since the average flow of the Clinch in the vicinity of the ORGDP site is 3102 Mgd [4808 cfs (1.36×10^5 liters/sec)], and most monthly averages for the past ten years exceed 646 Mgd [1001 cfs (2.8×10^4 liters/sec)],[44] the consumptive use of up to 12 Mgd [18 cfs (520 liters/sec)] is insignificant in comparison. Likewise, periods of zero flow are not likely to last long enough for appreciable drawdown to occur (Sect. 4.4.1.1). Because of changes in recent years in the regime for the release of water from Melton Hill Dam (Sect. 4.4.1.1), a $7Q_{10}$ flow for the Clinch has no real meaning. However, it is reasonable to assume that any low flow protracted over several days will still be large enough so that only a few percent (maximum) of that flow will be consumed by the operation of ORGDP. Moreover, any water-level fluctuations caused by the facility, even under extreme worst-case conditions (e.g., a month of zero flow), would be minimal compared with those induced routinely by the regulation of outflow from Melton Hill and Watts Bar dams (Sect. 4.4.1.1).

Current ORGDP discharges are not likely to affect industrial water use downstream; the effluent streams are essentially usable without dilution for cooling water makeup or process water makeup.

5.4 IMPACTS OF OFFSITE POWER PRODUCTION

The electrical generating capacity required to operate ORGDP in 1984 will be 2800 MWe (2080 MWe for maximum operation with about 35% reserve assumed). This power is supplied by the TVA. Since all contracts with TVA are for bulk power and do not require use of specific dedicated power plants, the environmental impacts of supplying ORGDP power can be considered as a proportion of the total environmental impact of the operation of the TVA network of hydroelectric, coal, combustion turbine, and nuclear generating facilities.

Table 5.26 gives the projected mix of generating facilities to be operational in 1984 when the full impact (cascade improvement and uprating programs completed) of ORGDP operation could be felt. Of the 42,618 MWe on the TVA network, ORGDP operation accounts for 6.57%. This includes 298 MWe of hydroelectric, 1170 MWe of coal fired, 1067 MWe of nuclear, 165 MWe of combustion turbine, and 100 MWe of pumped storage generating capacity.

These amounts of power are roughly equivalent to the typical size plant or single unit of each type. The approach taken in evaluating the impacts of supplying this power is to review and

Table 5.26. Tennessee Valley Authority generating capacity, 1984

No. of plants	Units	Installed capacity (MWe)	Percentage of total	Typical plant size
		Hydroelectric		
29	109	3,256	7.64	Fontana – 238.5 MWe; 3 units
20	Alcoa and U.S. Army Corps of Engineers' dams	1,277	3.00	
		Coal fired		
12	63	17,796	41.76	Gallatin – 1255.2 MWe; 4 units
		Nuclear		
5	11	16,249	38.12	Watts Bar – 2,539.80 MWe; 2 units
		Combustion turbine		
4	48	2,510	5.89	Gallatin – 325.2 MWe; 4 units
		Pumped storage		
1	4	1,530	3.59	Raccoon Mountain – 1,530 MWe; 4 units
Total		42,618	100	

Source: Tennessee Valley Authority, *A Power Annual Report for the Fiscal Year Ending September 30, 1977.*

summarize environmental impact analyses of each type of facility. Since ORGDP draws its power on a continuous base-load basis, the peaking-type facilities, that is, combustion turbine and pumped storage, have not been constructed in any way as a result of ORGDP. In fact, ORGDP regularly curtails its operation during seasonal periods of peak demand. Therefore, the impacts of these facilities are not discussed.

Hydroelectric. Environmental impacts of generating electricity by hydroelectric facilities result primarily at the time of construction of the dam and filling of the reservoir. A hydroelectric facility in the Tennessee Valley generating 300 MWe would likely inundate at least 550 acres of land, depending on the terrain (and therefore depth). This would result in loss of free-flowing river habitat, farms, and villages and riparian terrestrial habitat. These impacts would be partly offset by the recreational value of the reservoir and its associated wildlife habitats.

Other impacts created by such an impoundment would include formation of deep water pools, in turn creating physical, chemical, and biological changes. A biologically impoverished zone caused by the fluctuations of the reservoir's water level, alteration of downstream habitats, modification of fish migration (the large water body may also create a barrier to migration patterns of terrestrial animals), and imposition of stress and mortality to fish and wildife would also occur.[74]

Nuclear. A typical 1050-MWe nuclear generating facility requires about 1500 to 2000 acres of land for the site, of which about 250 acres is permanently disturbed. Minor loss of cropland and wildlife habitat sometimes results. About 5000 acre-ft of water are consumed annually, assuming such a plant uses closed-cycle cooling. Aesthetic degradation occurs due to cooling tower plume visibility. Land-use impacts can also occur from drift of salts and biocides in the plume.

Mining of the uranium to supply the nuclear reactors would result in the temporary commitment of about 55 acres of land per year if typical surface-mining techniques are used. About 2 acres per year would be permanently committed or about 60 to 100 acres over the lifetime of ORGDP. Other environmental problems related to uranium mining are air emissions, waste disposal, radon emissions, aesthetic degradation, trace-metal contamination, mine tailing deposition, and accident risks.[74] Environmental issues related to uranium milling are sulfate emissions, low-level radiological releases, radiological waste disposal (mill tailings), toxic trace metals, and water consumption.

To obtain a fuel enriched in uranium-235, the U_3O_8 concentrate first must be converted to the volatile uranium hexafluoride (UF_6). Uranium hexafluoride conversion facilities generate considerable amounts of atmospheric hydrogen fluoride (HF), a pollutant that has a documented capability to injure plants and particularly sensitive livestock. Other atmospheric and aquatic pollutants (e.g., NH_3, SO_2, H_2S) emitted from UF_6 conversion facilities normally are not produced in a great enough quantity to cause concern. HF emissions from older facilities can result in decreased productivity of plants and in fluorosis effects among nearby cattle, sheep, and poultry. Other impacts of UF_6 conversion facility operations have not been documented. Disposal of radioactive wastes from the 1050 MWe of nuclear generating capacity that can be allocated to ORGDP operation is a very minor portion of the total nuclear wastes generated, which, as a whole, are a national issue.

Typically, about 40 cfs of makeup water is required for cooling tower operation. Because large rivers and reservoirs are readily available within the Tennessee Valley, such a flow rate would not constitute a significant portion of the available supply. Therefore, impacts resulting from impingement and entrainment of biota would be unlikely to significantly reduce fish and plankton populations.

Radiological dose to the surrounding population would not be greater than 2% of natural-background radiation dose.

Coal. Impacts related to generation of 1200 MWe by a coal-fired generating facility result from mining, transportation, storage, combustion, and waste disposal. About 400 acres of land are required for a coal-fired generating facility.[75]

Annual land and water commitments for mining are given in Table 5.27. Acid mine drainage to surface-water and groundwater supplies, erosion and turbidity of streams, habitat destruction, and aesthetic degradation have resulted from underground and surface mining for TVA coal operations. The Surface Mining Control and Reclamation Act of 1977 sets forth procedures and rules to protect society and the environment from adverse effects of surface mining and surface impacts of underground mining. There is a high occupational risk associated with underground mining from both black lung disease and accidents.

Table 5.27. Annual impacts of coal mining on land and water

	Eastern surface mine	Western surface mine	Eastern underground mine
Land, acres/year	150	35	280
Water			
Consumptive, acre-ft	25	18	60
Nonconsumptive, acre-ft	670	210	670

Source: U.S. Department of Energy, *Environmental Data for Energy Technology Policy Analysis*, ASEV-OTI, Mitre Corporation, October 1978.

Coal is transported to TVA plants by barge, truck, and rail. Major environmental impacts are caused by fugitive coal dust and spills. Accidents and fatalities due to increased traffic and coal haulings have undoubtedly resulted from increased coal transportation due to ORGDP operations.

Effluents resulting from the combustion of coal depend largely on the type of coal and type of boiler used. The effluent releases typical of TVA plants are listed in Table 5.28.

Table 5.28. Air pollutants from north central Appalachian coal – 11,500 Btu/lb

	Amount (tons/year)		
	Gross	Plants under new source performance standards	Plants meeting state implementation plan
Particulates	1,000,000	2,000	5,000
Sulfur dioxide	110,000	28,000	80,000
Nitrogen oxides	21,000	16,000	21,000
Hydrocarbons	3,000	3,000	3,000
Carbon monoxide	1,000	1,000	1,000
Arsenic	19	16	
Cadmium	0.50		
Mercury	2.2	2.2	
Selenium	7	2.0	
Manganese	330	18	
Radioactivity[a]	Curies per year		
^{238}U chain	0.14		
^{235}U chain	0.06		
^{232}Th chain	0.9		
^{222}Rn	14.4		
^{220}Rn	7.2		

[a]Data from J. P. McBride et al., "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants," *Science* **202**, 1045–1050 (1978).

Source: U.S. Department of Energy, *Environmental Data for Energy Technology Policy Analysis*, ASEV-OTI, Mitre Corporation, October 1978.

Water pollutants result primarily from runoff of coal storage piles and effluents from fly-ash and bottom-ash ponds. Many heavy metals, organic contaminants, and other potentially toxic substances are washed into surface water bodies from storage piles and ash ponds. Such contamination often affects the pH and other physical and chemical parameters of receiving waters. Losses of aquatic habitat and biota are well documented at ash pond outfalls.[76]

Health impacts of coal combustion are the subject of extensive and continuing study. Investigators generally accept a causal relationship between air pollution and adverse health effects. The classic air pollution episodes in the Muese Valley, Donora, and London have clearly demonstrated that exposure to high levels of airborne combustion products has adverse effects on health.[76] However, there is less firm agreement on the actual quantitative form of such relationships, and many problems arise during attempts to estimate them.

The report of the Committee on Health and Environmental Effects of Increased Coal Utilization (the Rall Report)[77] identifies three possible health issues resulting from coal use: (1) increased respiratory disease from acid sulfate production, (2) the possible link between urban air concentrations of polycyclic organic matter and the incidence of lung cancer, and (3) the potential health impacts from trace substances in ash.

The principal components of the emission stream have known effects on human health, including physiological irritation and direct toxicity. A carcinogenic potential has also been postulated for these emissions.

5.5 POTENTIAL ACCIDENTS

The various types of credible accidents described in Sect. 2.2.5 are assessed below.

For an evaluation of radioactive releases, potential doses to individuals were calculated for postulated accidents in the enrichment plant and for accidents associated with transportation. The methodology and dose factors used in these calculations were essentially the same as those used to calculate doses due to radionuclide releases from the plant during normal operation. For normal releases, the dose per year of operation was calculated. For accidental releases, the total potential dose per accident was calculated.

Since accidents occur over a short time period, average meteorological conditions cannot be assumed. Therefore, the staff pessimistically selected the meteorological conditions of Pasquill stability category D, with a low wind speed of 1 m/sec. For process and handling accidents, doses to individuals at the nearest area open to the public (a parking lot 150 m from effluents) were calculated. For transportation accidents, doses to individuals at a 150-m distance were calculated. In assessing potential accidents, the most conservative assumptions are made. As a result, the calculated dose to an individual tends to be high.

The highest total-body dose received by an individual at the site boundary during an accident was 65 rems (Case 2 UF_6 handling, Table 5.29 and Sect. 5.5.4). To estimate a statistical risk of death from radiation-induced cancer, the dose–cancer mortality conversion factor for uniform whole-body irradiation (1.0×10^{-4} deaths per rem of dose) as recommended (in Report 26) by the International Commission on Radiological Protection (ICRP) was used. This leads to an estimated mortality risk of 0.0065 for that individual exposed during the worst credible UF_6-handling accident.

Table 5.29. *Estimated doses from UF_6 process and handling accidents at ORGDP*

Accident description	Dose (millirems)			
	Total body	Bone	Kidneys	Lungs
Diffusion process[a] (compressor failure)	2.5E3[b]	2.8E4	1.2E3	1.0E2
UF_6 handling				
Case 1[c]	3.0E−4[d]	5.0E−3	1.2E−3	
Case 2[a]	6.5E4	7.5E5	3.2E4	2.7E3

[a] Maximum doses at 150 m from release; at 1000 m, doses are reduced by a factor of 25.

[b] Read as 2.5×10^3.

[c] Doses due to ingestion of contaminated drinking water.

[d] Read as 3.0×10^{-4}.

Tables 5.29 and 5.30 give the estimated total-body and organ doses for plant and transportation accidents respectively. Since current studies such as the BEIR Report of the National Academy of Sciences[62] indicate that no other living organism is known to be very much more radiosensitive than man, the staff has not calculated doses to biota.

Releases of HF gas associated with the postulated accidents are of potentially greater hazard to man and other biota than is the uranium (as UO_2F_2). Tables 5.31 and 5.32 give the HF concentrations in the environment for process and handling accidents and transportation accidents respectively. Although these concentrations in air may not last for long, all of them fall within the 2.5 to 1.0×10^2 mg/m^3 range considered to affect man.[78] For comparison, the daily

Table 5.30. Estimated doses from UF_6 transportation accidents at ORGDP

Accident description	Dose (millirems)			
	Total body	Bone	Kidneys	Lungs
Case 1[a]				
Airborne release — normal-assay uranium	1.1E3[b]	1.2E4	5.3E2	4.5E1
Case 2[a]				
Airborne release — normal-assay uranium				
90% solid	1.3E2	1.5E3	6.5E1	5.5
20% solid	1.1E3	1.2E4	5.3E2	4.5E1
Case 3[c]				
Punctured cylinder enters water body	4.5E−3[d]	7.3E−2	1.7E−2	

[a]Maximum doses at 150 m from release; at 1000 m, doses are reduced by a factor of 25.

[b]Read as 1.1×10^3.

[c]Doses due to ingestion of contaminated drinking water.

[d]Read as 4.5×10^{-3}.

Table 5.31. Estimated concentrations in air and water of HF gas released in ORGDP process and handling accidents

	Release rate (kg/sec)	Duration of release (min)	Amount released (kg)	Concentration (mg/m^3)
Diffusion process (compressor failure)	0.86	6	3.1E2[a]	4.3E2[b]
UF_6 handling				
Case 1	2.3	20	2.8E3	1.4E4[c]
Case 2	1.8	15	1.7E3	2.3E3[b]

[a]Read as 3.1×10^2.

[b]Concentration in air at 150 m from release point; concentrations at 1000 m are reduced by a factor of 25.

[c]Concentration in Clinch River at a flow of 6000 cfs, released as UF_6 through condensate line, forming UO_2F_2 and HF.

8-hr occupational exposure limits for HF are 2.5 mg/m^3, with tolerable exposures of several minutes duration to 25 mg/m^3 and lethality at 1.0×10^3 mg/m^3. It is unlikely that anyone would remain in the area of release for more than a few minutes.

Atmospheric HF induces visible injury to green plants during short exposures (one to several hours) at concentrations of 0.5 to 10 mg/m^3.[78,79] Unfortunately, there are no studies describing atmospheric HF concentrations that cause lethal effects. Potential impacts of accidental HF releases to the atmosphere would be severe. The effects of HF on vegetation, animals, and man have been reviewed in two reports.[78,79] The discharge of fluorides in excess of 1.5×10^3 mg/m^3 can be expected to have serious short-term consequences on aquatic ecosystem components. For example, local fish kills could occur if fluorides at concentrations of 1.0×10^4 mg/m^3 or greater are released in aquatic systems.

Table 5.32. Estimated concentrations in air and water of HF gas released in ORGDP transportation accidents

Accident description	Release rate (kg/sec)	Duration of release (min)	Amount released (kg)	Concentration (mg/m^3)
Case 1 — airborne release, fire with cylinder puncture	3.7E2[a]	102	2.3E3	20.4[b]
Case 2 — airborne release, fire with cylinder explosion				
90% solid	1.8E2	240	2.8E3	9.9[b]
20% solid	7.9E2	60	2.8E3	43.3[b]
Case 3 — release of normal-assay uranium to stream with flows (in cfs) of:				
100	1.2[c]	180	1.2E4[c]	9.5E4
1,000	1.2	180	1.2E4	9.5E3
10,000	1.2	180	1.2E4	9.5E2

[a] Read as 3.7×10^2.

[b] Concentration in air at 150 m from release point: concentrations at 1000 m are reduced by a factor of 25.

[c] Released as UF_6.

5.5.1 Criticality accidents

Accidents involving criticality are highly improbable, primarily because of the low enrichment of the fissile material being handled. Criticality accidents that may occur were discussed in some detail in Sect. 2.2.5.1. Radioactive releases from a criticality accident are likely to be contained by the process equipment or the building; only minor contamination would occur in the immediate vicinity. Therefore, no exposure to the general public from such an accident is anticipated.

5.5.2 Diffusion process accidents

Releases of UF_6 due to a failure in the process equipment, particularly the compressor, could be extensive. The releases hypothesized in such an accident were described in Sect. 2.2.5.2.

Maximum individual doses from an accident involving an assay of 1% uranium-235 and an air change every 6 min are shown in Table 5.29.

Uranium-234 and -238 contribute 57% and 40%, respectively, to the bone dose. Inhalation is the predominant pathway of exposure (100%).

The concentration of HF in air at the nearest plant boundary is given in Table 5.31. Death to green plants is likely at unknown distances from the compressor failure, with leaf-spotting injuries occurring at 1000 m or more (Table 5.31).

5.5.3 Centrifuge process accidents

As discussed in Sect. 2.2.5.3, the worst credible release of UF_6 from a centrifuge accident would result in a much less severe impact than would the worst credible release from a diffusion process accident. Although atmospheric releases during a centrifuge process accident have not been quantified, they are likely to be less than those associated with a diffusion process accident (Sect. 5.5.2). Radioactivity releases would be of greatest concern, although prevention of release of toxic substances would also require mechanical and personnel attention.

5.5.4 UF_6-handling accidents

Case 1. Releases of UF_6, in the form of UO_2F_2 and HF, into Poplar Creek as a result of a hydraulic rupture in a 14-ton cylinder could contaminate drinking water taken from the Clinch River. It is assumed that a person drinks 2 liters of water from the Clinch River while the river is at its peak activity concentration during normal flow. Doses are not computed for the Poplar Creek concentrations since this area normally would not be open to the public. Table 5.29 gives the estimated maximum individual doses resulting from ingestion of a 2-liter sample from the Clinch River following an accident of this nature.

Uranium-234 contributed 77% of the total-body dose and 76% of the bone dose. Even at extremely low flow in Poplar Creek or the Clinch River, the radiological impact of this accident is very small.

The concentration of HF in the Clinch River is given in Table 5.31. Some fish kill would likely occur in the Clinch River.

Case 2. Atmospheric releases of UF_6 as a result of a cylinder rupture produce UO_2F_2 and HF upon reaction of the UF_6 with moisture in the air. An accident of this type is described as case 2 in Sect. 2.2.5.4.

Maximum individual doses occur 150 m from the point of release — in a parking lot adjacent to the plant perimeter. Estimated doses are listed in Table 5.29.

Uranium-234 and -238 contribute 70% and 24%, respectively, to both the total-body and bone doses. The critical exposure pathway is inhalation (100%).

Exposures to HF at the parking lot, 150 m from the postulated accident, could be seriously high (see case 2 in Table 5.31) if the exposures were for more than a few minutes. Effects on green plants would be considerably worse than those from the diffusion process accidents (Sect. 5.5.2). Terrestrial vertebrate animals are unlikely to be affected in either hypothetical release case because they do not inhale at a rate rapid enough to cause injury.[78] However, at the nearest site boundary (2.5 miles southwest of the plant), the same accident would result in concentrations in air several orders of magnitude lower and would not result in any significant exposure. Most effects would occur within the plant boundary and would not greatly affect offsite land use.

The concentration of HF in air is given in Table 5.32.

5.5.5 UF_6 transportation accidents

Case 1. A punctured 14-ton cylinder is hypothesized for this transportation accident. The resultant fire causes the UF_6 in the cylinder to vaporize and subsequently enter the atmosphere through the point of rupture; reaction with moisture in the air results in UO_2F_2 and HF. Releases from this type of accident are discussed in Sect. 2.2.5.5.

Maximum individual doses resulting from this accidental release are listed in Table 5.30. Uranium-234 and -238 contribute 47% and 51%, respectively, to the total-body and bone doses. Inhalation is the critical pathway of exposure (100%). This dose calculation assumes a release 20 m above ground due to the buoyancy of gases from the fire. The maximum dose occurs 150 m from the point of release, but is reduced by a factor of 25 at a distance of 1000 m.

The concentration of HF in air is given in Table 5.32.

Case 2. This accident also involves a ruptured 14-ton cylinder. The resultant fire causes the cylinder to explode and release UF_6 to the atmosphere, where it forms UO_2F_2 and HF. The amounts released when 90% and 20% of the UF_6 remained in solid form are described in Sect. 2.2.5.5.

Maximum doses estimated for the case in which 90% of the UF_6 remained as a solid are given in Table 5.30. Uranium-234 and -238 are responsible for 47% and 51%, respectively, of the total-body and bone doses; inhalation is the critical exposure pathway (100%). Since the radioactivity released when a small portion (20%) of the UF_6 remains in solid form is the same as in case 1, the radiological impact would be similar.

The concentration of HF in air is given in Table 5.32.

Case 3. The third transportation accident is hypothesized to result when a carrier containing a punctured cylinder falls into a stream. The UF_6 in the punctured cylinder reacts with the water to form UO_2F_2 and HF — amounts formed are discussed in Sect. 2.2.5.5.

Maximum individual doses from drinking 2 liters of this water are listed in Table 5.30.

Uranium-234 and -238 respectively contribute 51% and 47% of the total-body dose. Ingestion of contaminated water is responsible for 100% of the dose to all organs.

Stream concentrations of HF are given in Table 5.32. Some fish kill would likely occur.

5.5.6 Chemical releases

Only one of the nonradiological accident scenarios depicted in Sect. 2.2.5.6 results in an effect on the aquatic environment (none of the other scenarios involves releases to the stream systems). The potential release to Poplar Creek of up to 12 million gallons of cooling water containing about 10 ppm hexavalent chromium (Cr^{6+}) is hypothesized under four different conditions of flow and release rates. Two cases assume essentially zero flow in both Poplar Creek and the Clinch River, and the other two presume average flow. Under each flow regime, total release rates of 15 min and 5 hr are assumed. The resultant concentrations of Cr^{6+} to be expected in the streams for each case are given in Table 2.21. For cases 1 and 3 (no flow; 15-min and 5-hr release rates respectively), it is conceived that these concentrations will be present within a wedge of essentially undiluted water extending for several hundred feet into the Clinch River (Sect. 2.2.5.6). For cases 2 and 4 (average flow; 15-min and 5-hr release rates respectively), the concentrations given in Table 2.21 are those that would occur after complete mixing of the discharge in Poplar Creek and the Clinch River.

All the concentrations hypothesized to occur in the various cases would be detrimental to aquatic biota. There is a great range in sensitivity to chromium among different species, but cases 1 and 3 would result in the receipt of lethal doses by many organisms within the "wedge," including many of the invertebrates and algae.[80] The fish present might escape harm, although the chronic effects from the accumulation of chromium in body tissues are not well known. Likewise, the concentrations encountered in cases 2 and 4 are large enough to induce acute toxicity in many lower organisms. However, several species would likely be unaffected by the case 4 Clinch River concentration (0.18 ppm).[54] A reduction in the biomass of organisms in the lower trophic levels could lead to concomitant reductions in the standing crops of fish and other consumers.

The release of this large a quantity of chromium-laden water would seriously alter the biotic communities of the Clinch River and Poplar Creek for several miles downstream. Toxicity (chronic and acute) could be expected in at least some biotic components until the concentration is reduced to about 0.05 ppm, or less. After dilution of these levels, the communities would likely slowly recover to the characteristic states displayed before the accident. However, chromium left in the sediments and in organisms (by bioaccumulation and direct uptake) might exert chronic toxic effects (e.g., reproductive impairment) for some time.[80]

The water would remain unpotable until the chromium levels dropped to 0.05 ppm, or less.[80]

Effects of accidental chemical releases [AHF spill from storage tank rupture (Sect. 2.2.5.6)] on terrestrial biota are difficult to evaluate because no data exist to suggest doses that are damaging or lethal to green plants and animals during the hypothesized <10-min period of release. From release data in Fig. 2.19 and from χ/Q values in Table 5.25, the staff estimates that HF air concentrations following the HF flash would be 123 mg/m^3 at 1 km, 41 mg/m^3 at 5 km, 19 mg/m^3 at 10 km, and 8 mg/m^3 at 20 km, during the first 3 min of HF release. If these short-duration concentrations affect plants in the same manner as do longer-duration concentrations, visible leaf damage would occur on plants considerably beyond the 20-km radius of the spill, and lethal doses would be incurred over some unknown portion of this distance.

Vigorously working humans inhale about 0.1 m^3 of air in 5 to 10 min,[78] or a maximum of about 12.3 mg of HF at 1 km from the hypothetical spill site. Acute fluoride poisoning is estimated to occur at 2500 to 5000 mg of NaF, the most toxic fluoride compound,[78] although the minimal symptomatic dose is 50 to 100 mg.[78] Other animals are likely to suffer less than man from HF inhalation.[78]

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6. UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECTS

Impacts to terrestrial systems that occur off the Oak Ridge Reservation are limited. Cooling tower plumes are visible offsite, and they occasionally touch the ground. The frequency of ground-level fogging along Tennessee Highway 58 adjacent to the Oak Ridge Gaseous Diffusion Plant (ORGDP) is estimated to be 16% greater than the frequency of fog without operation of the facility (Sect. 5.3.1). No other significant unavoidable adverse impacts of ORGDP operation are likely to occur off the reservation.

Unavoidable adverse impacts of ORGDP operation that may occur on the Oak Ridge Reservation near the plant are primarily a function of air quality deterioration. Under normal atmospheric conditions, cooling-tower-drift salts are the only atmospheric pollutant from the plant likely to induce significant impacts. The combined deposition of salts from cooling tower drift and from natural sources could reduce natural plant growth on as much as 500 acres of land near ORGDP.

Under severe meteorological conditions, Tennessee ambient air quality standards for hydrogen fluoride (HF) may be exceeded near ORGDP (Sect. 5.3.1). No adverse impacts of the HF excesses are likely to result to land use, biota, or humans. Deterioration of building surfaces, corrosion of metal, discoloration of paint, and destruction of textiles at the ORGDP site may also result from conversion of atmospheric SO_2 to its acid forms during periods of precipitation (Sect. 5.3.1).

Radioactively contaminated wastes will fill 20 acres of land, and 2 acres will be used for sanitary landfill (Sect. 5.3.2). No other significant adverse impacts on terrestrial systems are likely to occur on reservation land from ORGDP operations.

The current (and projected) operation of ORGDP contributes to the chemical loading of Poplar Creek and the Clinch River (Sect. 5.3.3). During periods of low or zero flow, the quantities released may induce severe local aquatic impacts (toxicity, eutrophication) (Sect. 5.2.2), but the effects from such episodes should be transient, with the possible exception of increased heavy-metal body burdens. During periods of average flow, no significant impacts are likely from the effluents alone, but toxicant additions may incrementally affect organisms exposed to high ambient toxicant levels (Sect. 5.2.2).

The total population living within 50 miles of ORGDP is projected to receive a total-body radiation dose of 0.044 man-rem per year in 1984. This is only about 0.00006% of the dose received by this population from natural background in the state of Tennessee. Maximum annual dose estimates for offsite individuals are 0.0037 millirem for the total body and 0.00023 to 0.041 millirem for organs, the highest value being for bone (85% of the bone dose can be attributed to uranium-234).

7. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Irreversible commitments of resources concern changes that, at some later time, cannot be altered so as to restore the original order of environmental resources. Some resources that may be irreversibly committed are biota that are destroyed, materials that cannot be recovered or recycled, and land that is rendered unfit for its previous use.

Irretrievable commitments of resources include the consumption of resources that cannot be renewed or recovered for subsequent use. Such resources include both material resources and human resources.

Abiotic resources. The land on which the Oak Ridge Gaseous Diffusion Plant (ORGDP) stands is neither irreversibly nor irretrievably committed. The continued operation of ORGDP represents a specific continued commitment of about 640 acres for the facilities and includes buildings, roads, railroads, parking lots, holding ponds, burial grounds, lawns, and buffer zones. This is less than 2% of the 37,300-acre reservation which has been set aside for projects of interest to the U.S. Department of Energy. Recovery of this land for reuse after decommissioning of the facility is primarily a matter of economics. For example, growth of food crops over the burial grounds might be restricted if the cover depth were inadequate; however, adequate fill could be added for resumption of any natural use of the land. The land currently committed to the classified burial ground is 22 acres and contains about 0.2 Ci of low-level uranium wastes (Sect. 2.2.3.3).

About 24 Mgd of water from the Clinch River will be committed to ORGDP use by 1984 (Sect. 5.3.4). This water is unavailable for use by other customers in the area, but there is a total of 3100 Mgd of water available during average flow of the Clinch River. Of the water withdrawn, 25% will be returned to the river in the form of blowdown and various waste streams.

ORGDP will continue to replace worn-out and broken equipment and will continue to consume other materials during normal operations. All scrap metal is recovered, and radioactively contaminated metal is stored in anticipation of ultimate recovery (Sect. 2.2.3.3). Other materials consumed include (1) gasoline and fuel that is used primarily for transportation, (2) lubrication oil and fluorocarbon coolants that may be lost from plant systems, and (3) chemicals used in water treatment.

About 2080 MW of electricity will be used by ORGDP in 1983. Thus the coal and uranium used to generate this electricity will be irreversibly committed.

Biotic resources. The human resources used (employment, about 4500) in operating and maintaining ORGDP are irretrievably expended. Gaseous and liquid effluents are discharged from ORGDP, but the concentration of pollutants in the air and water outside the plant boundary do not exceed minimum concentrations that are known to be harmful to biota.

No rare or endangered terrestrial plant or animal species are known to grow within 3000 m of the plant. Continued operation of the plant is not expected to contribute to destruction of such species. The liquid effluents from the plant do not significantly affect the distribution or abundance of any rare or endangered aquatic species.

8. RELATIONSHIP OF LAND-USE PLANS, POLICIES, AND CONTROLS

Ownership of the Oak Ridge Reservation has been retained by the federal government to accommodate projects of interest to the nation. Since local land-use plans do not apply to land within the reservation, there is no conflict between the U.S. Department of Energy's current use of the land and local or state land-use plans and policies. Likewise, the continued operation of Oak Ridge Gaseous Diffusion Plant (ORGDP) is not in conflict with any federal land-use plans, policies, or controls.

The Oak Ridge Reservation land-use plan[1] incorporates in-depth ecological concepts that recognize multiple uses of land as a viable option. Neither environmental research nor technological operations need be mutually exclusive in all instances. Unique biological areas, as well as rare and endangered species, are protected, and human and environmental health and safety are maintained. The ORGDP site comprises some 4720 acres (1911 ha), including a 1-mile-radius (1.6 km) buffer zone of 2980 acres (1206 ha). Expanded DOE activities will intensify the use of existing land resources and may require the acquisition of additional land in the future. The land-use plan[1] identifies and describes current, projected, and potential land-use requirements and serves as the basic document for decision making regarding land use, acquisition, and disposal consistent with federal laws and regulations.

The Clean Air Act requires federal facilities to comply with federal, state, regional, and local air pollution control regulations.

The National Pollutant Discharge Elimination System established eight liquid-effluent permits and associated standards, monitoring, and reporting requirements for the ORGDP. Appropriate corrective actions are taken whenever concentrations in the effluent are found to exceed permit limits.[2]

REFERENCES FOR SECTION 8

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9. RELATIONSHIP BETWEEN SHORT-TERM USES OF THE ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

There is significant local social and economic benefit to the surrounding communities from the continued operation of the Oak Ridge Gaseous Diffusion Plant (ORGDP). The monies from the plant payroll find their way into the communities and support community services and businesses.

Some local effects of continued operation of ORGDP tend to oppose environmental productivity through impacts on land, water, and air. Some of the areas within the plant boundaries are partially restrained from biological production, resulting in a loss of habitat for birds, small mammals, and deer. The continuing use of the land for operation of the plant represents a small loss of cropland for food production. The materials used during the operation of the plant represent an irretrievable commitment of natural resources. The water withdrawn from the Clinch River has a small, but not significant, effect on local water supplies. Chemical and thermal releases from the plant to the air and water may adversely affect the biological productivity in adjacent regions, especially during short-term severe meteorological conditions. Among these effects are (1) fogging and salt deposition resulting from cooling tower operation and (2) discharge of biocides into the Clinch River.

Continued operation of ORGDP may result in environmental losses at other sites as a result of uranium mining and processing. Impacts on the environment occur from toxic trace metals from mining and processing operations. It has been found that uranium-mill tailings located at active and inactive mills may pose a potentially significant radiation health hazard to the public; the protection of the public health, safety, and welfare and the regulation of interstate commerce require that every reasonable effort be made to provide for the stabilization, disposal, and control of such tailings in a safe and environmentally sound manner to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards from the tailings. The Uranium Mill Tailings Radiation Control Act of 1978 (H.R. 13650) proposes a program to accomplish these objectives. The act is intended to minimize the dispersal of radioactivity from past operations by proper remedial actions and tails management. Also, the radioactive wastes produced by the nuclear industry that is supported by ORGDP represents a long-term environmental loss in that they require the continuing expenditure of manpower for waste management.

The depleted uranium tails withdrawn from ORGDP are stored indefinitely in 10- or 14-ton cylinders as solid UF_6. This material is a valuable resource, serving as a source of depleted uranium, or uranium-235 if the decision is made to process the tails to lower uranium-235 assay. The fraction of uranium-235 removed in the diffusion process is directly related to the useful energy produced and inversely related to the amount of mining and milling tails produced. Thus the mining and milling environmental impacts are relatively less as the tails assay of uranium-235 goes down, because less uranium is required for a given amount of useful energy extracted. As uranium becomes more scarce and expensive, it may be economically advantageous to remove a greater fraction of the uranium-235 from the tails.

The short-term use of the land near the junction of Poplar Creek and the Clinch River has been to produce enriched uranium. This enriched uranium is used primarily for the generation of electricity by nuclear reactors. These reactors contribute significantly to the benefit of the United States in two ways: (1) by decreasing the amount of oil needed for oil generating plants (positive effect on the U.S. balance-of-trade deficit) and (2) by decreasing the demand for coal-fired generating plants (positive effect on air pollution, since nuclear plants pollute less than do coal-fired plants). Also, ORGDP has contributed significantly, both past and present, to the development of the gas centrifuge technology which is to be put into commercial operation in Ohio.

In the long term, ORGDP may be retired upon termination of its current use, and the land now in use could be returned to agricultural farmland if decommissioning included removal of all structures. Experience in equipment retirement indicates that the decommissioning of ORGDP will not introduce any technical, safety, or environmental problems that differ significantly from those occurring during operation and maintenance.

10. TRADE-OFF ANALYSIS

Operation of the Oak Ridge Gaseous Diffusion Plant (ORGDP) can be categorized in terms of a trade-off between local environmental and socioeconomic costs and socioeconomic and technological benefits, which have local and national impact.

10.1 COSTS

Environmental costs are summarized (Table 10.1) according to:

1. impacts from the existence and operation of ORGDP and the offsite power plants that serve it, transmitted via natural water bodies, the air, and the land
2. consumption of natural resources

In general, there is no manifestation of major environmental costs to the Oak Ridge area caused by the operation of ORGDP. Most of the aquatic impacts measured have been relatively small (Table 10.2). High concentrations of mercury and polychlorinated biphenyls (PCBs) in the sediment of the Clinch River and Poplar Creek are probably not attributable to ORGDP. Atmospheric impacts are small and only locally effective even when potential air quality deterioration from fluorine, sulfur dioxide (SO_2), and cooling-tower drift emissions has been considered.

The socioeconomic costs associated with ORGDP should be viewed within the context of the socioeconomic environment brought about by the presence of the entire federal complex at Oak Ridge. The three local entities predominantly affected by this complex are Anderson and Roane counties and the city of Oak Ridge. When the federally created community of Oak Ridge was established as part of the Manhattan Engineer District program, the two counties felt the impacts of the wartime influx of workers and their families, thousands of daily commuters to the project, and the shortages of manpower and financial resources with which to respond to the new burdens.

Population increases in the early years of the federal project were dramatic for Anderson County and for what came to be the Oak Ridge community. The Anderson County population jumped from 26,504 in 1940 to 59,407 in 1950, while Oak Ridge mushroomed to about 75,000 in 1945 before settling down to a postwar level of 30,000. Roane County experienced a smaller increase in population, 13.9%, in the 1940-1950 decade, although in recent years its federally related population has been increasing more than has that of Anderson. (Population trends since 1940 are shown in Table 10.3.) In a broad sense, the presence of the federal installations and the skills and educational requirements necessary for the U.S. Department of Energy (DOE) programs have accelerated the transformation of the character of two counties from rural and agricultural to urban. The influences of the federal enterprise on income, occupations, and educational levels in the two counties are discussed in depth in a University of Tennessee study prepared for the U.S. Atomic Energy Commission.[1]

This influx of people increased the work load on county governments, principally in the fields of legal services, road maintenance, and education. Some idea of the magnitude of the increased use of roads can be obtained from Table 10.4, which shows the number of license plates sold in the county immediately before the establishment of Oak Ridge; at the height of employment, 1944 to 1945; and in 1972. Since road maintenance costs are borne by county shares of the state tax on motor vehicle fuels, they have not been considered as a significant burden in this analysis.

Burdens on the school systems started with the influx of workers who settled in both the rural and urban areas of the counties. High-quality school curricula have been sought by the population for their own families and by the management of the federal complex in the interests of attracting the highly trained specialists necessary for Oak Ridge operations. The city of Oak

Table 10.1. Principal environmental costs of ORGDP

Population or resource affected	Description
Natural surface water	
Consumption of local water supplies (1984)	The enrichment plant will draw 20 Mgd for process cooling and 4 Mgd for sanitary water from the Clinch River (average river flow, 3100 Mgd) but will return 25% of it. The 24 Mgd withdrawn is <1% of the average river flow. The 18 Mgd consumed by ORGDP is an insignificant amount
Impact on aquatic biota	Not significant
Impact on water use	None
Impact on people	None
Thermal discharges	
Heat to water body	Discharge to the Clinch River is 1.7° to 3.3°C above the ambient Clinch River temperature. Plume is 6 to 9 m wide and its maximum depth is 1 m. The warmer water does not reach the river bottom. The plume is detectable only 12 to 18 m downstream from the discharge point. The plume from a small discharge into Poplar Creek is virtually undetectable
Impact on aquatic biota	No significant impacts but highly localized ones are possible, e.g., phytoplankton community composition changes, attraction of fish during colder months, cold shock of fish during power cutbacks, changes in photosynthesis rates, and enhancement of respiration/decomposition
Impact on people	None
Chemical effluents[a]	
Chemical water quality	
Biocides (chlorine residual)	Average Clinch River concentration becomes 0.0003 mg/liter, based on average stream flows
Sewage treatment plant effluents	Decrease in dissolved oxygen content in Clinch River is insignificant considering the size of the river and the quality of the water
Other chemicals	Concentration increases in the Clinch River, based on average stream flows, are very small (see Table 10.2)
Impact on industrial use downstream	None
Impact on aquatic biota	During periods of low or zero stream flow, discharges may induce transient local eutrophication and toxic effects on some biota
	At average stream flow, there is no significant impact likely but ORGDP discards can add incrementally to the high heavy-metal concentrations in streambed sediment and fish already contaminated by the high chemical backgrounds in Poplar Creek. Some Poplar Creek fish have been found to have mercury and PCB contamination exceeding maximum FDA recommendations for human consumption, but ORGDP may not be the major source of those contaminants. The background contamination is unrelated to current ORGDP discharges or process operations
Impact on people	Hypothetically, at low flow, discharges from ORGDP might raise the mercury concentration in the section of Poplar Creek from ORGDP to the creek/Clinch River junction to above the maximum for drinking water. Of course, water is not withdrawn for human consumption from this short section of the creek. This excessive concentration would occur if the upstream mercury concentration were already close to the maximum level, 2 μg/liter, as detected in recent tests
Impact on wildlife	Not significant
Radionuclides discharged to the Clinch River[b]	
Quantity, Ci/year	U-234, 0.2; U-235, 0.009; U-236, 0.003; U-238, 0.1; Tc, 3
Dose to aquatic biota (internal), millirads/year	
Aquatic plants	1.5E3[c]
Invertebrates	1.5E2
Fish	1.5E1
Waterfowl and muskrats	2.1
Individual dose to people (total body), millirem/year	3.2E−5[d]

Table 10.1 (continued)

Population or resource affected	Description
Hypothetical	
External (swimming 1% of the year)	1.7E−9
Internal (drinking 1.2 liters/day)	2.7E−5
Internal (eating 20 g/day of fish caught in the Clinch River)	4.5E−6
Impact of dose to aquatic biota	Significance of estimated radiation doses to aquatic biota has not been established. No known living organisms are very much more sensitive to radiation than man
Impact of dose to people	Doses from all aquatic pathways to total body and organs are well below 1 millirem/year and do not add significantly to the individual total dose
Groundwater	No impact
Air	
Heat discharged to the air from ORGDP cooling towers (1984)	1.5E11 Btu/day
Fogging and icing caused by cooling tower evaporation and drift	About 4 kg/sec of drift emitted (drops of water from the recirculating tower water); contains dissolved salts. Most deposition occurs within 400 m of the towers. Drift concentrations in air 100 m away are 0.001 μg of chromium, 0.07 μg of calcium, and 0.1 μg of magnesium, per cubic meter
Cloud development (visible plume)	Typical plume height is 100 to 200 m with a downwind reach of about 100 to 200 m. The maximum downwind extension is about 600 m. Plumes initiate clouds 10% of the time
Fog development	Fogging frequency in the vicinity of ORGDP possibly increased – no more than 300 hr/year. Fog observed at up to 3 km from the towers. Impact generally minor except within limited radius of ORGDP
Impact on vegetation	Vegetation up to 2 km from tower contains zinc and chromium levels above background, but no damage noted at the plant
Impact on transportation	16% increase in fogging possible along highways adjacent to ORGDP. Icing potential 300 to 350 hr/year, November through March
Chemical discharges to ambient air	Currently, HF levels in the ORGDP area exceed the 30-day average Tennessee standard 1 to 2 weeks/year. Because of plant upgrading, HF discharges will be decreased by 8% by 1984
Quantity, g/year	Particulates, 3.8E5; SO_2, 1.3E5; NO_x, 1.3E6; HF, 9.0E5; U, 140
Impact on vegetation and domestic animals	Elevated values of fluorine, chromium, and zinc occur in Oak Ridge Reservation vegetation, but concentrations that occur beyond reservation boundaries are insufficient to damage vegetation, crops, timber, or domestic animals. Vegetation on reservation property, building surfaces, paint, and metals can be damaged by fluorine and SO_2. Some SO_2 damage may be found on private land up to 7 km away. Salts from cooling-tower drift could reduce natural plant growth on 500 acres of reservation land near ORGDP. No impact from NO_x emissions
Impact on wildlife	Elevated values of fluoride in small reservation animals occur without apparent injury but greater impact by fluorine possible on predators further up the food chain
Impact on people	None
Impact on private buildings	None beyond the plant buffer zone
Radionuclides discharged to the ambient air	
Quantity, Ci/year	Tc-99, 2E−6; U-234, 5.5E−4; U-235, 1.7E−5; U-236, 9.0E−7; U-238, 9.0E−5
Dose to people (total body)	
Individual, millirem/year	3.7E−3
Population (50-mile radius), man-rem/year	4.4E−2
Submersion	
Individual at boundary, millirem/year	1.1E−10
Population (50-mile radius), man-rem/year	9.3E−10
Contaminated ground surface	
Individual at boundary, millirem/year	1.4E−4
Population (50-mile radius), man-rem/year	2.0E−3
Inhalation	

Table 10.1 (continued)

Population or resource affected	Description
Individual at boundary, millirem/year	5.2E−4
Population (50-mile radius), man-rem/year	4.6E−3
Ingestion (terrestrial food chain)	
Individual at boundary, millirem/year	3.0E−3
Population (50-mile radius), man-rem/year	3.8E−2
Natural background radiation	
Population (50-mile radius), man-rems year	68,300
Impact	All annual individual doses are well below 10 CFR Part 20 limits and future 40 CFR Part 190 standards. Ingestion is the predominant exposure pathway for total body and all organs except lungs, for which the highest dose comes from contaminated surfaces. Population dose is much lower than natural background
Land	
Amount of land preempted	
ORGDP	640 acres (not irreversibly committed)
Transmission lines (1984)	1700 acres
Impact on people (amenities and aesthetics)	15- to 175-ft-wide cleared power line rights-of-way on about 3% of the Oak Ridge land area
Impact on natural environment	None
Pesticides and herbicides used	Annual uses total about 4000 lb of herbicides and 65 gal of pesticides
Impact on people	None
Impact on natural environment	Not significant. Limited local control of weeds and pests in critical operating areas
Plant operations	
Impact on local streets	Traffic congestion occurs for short periods during rush hours and shift changes (about ½ hr each time)
Impact on people (amenities and aesthetics)	ORGDP has a neat, well maintained appearance from all public points of view
Impact on municipal services	No cost impact. ORGDP operates independently of the municipal services of local governing bodies
Solid radioactive wastes	
Quantity	14.2 Ci has been buried at various sites at ORGDP since the plant was built. Scrap metal containing an unknown amount of contamination is stored aboveground also
Impact on people, plants, animals	Not significant
Offsite power production (TVA)	10.64% from hydroelectric, 41.76% from coal-fired, 38.12% from nuclear, 5.89% from combustion turbine, and 3.59% from pumped storage facilities
Quantity	2800 MWe (maximum)
Hydroelectric power fraction	
Hypothetical quantity generated	About 300 MWe
Amount of land preempted	550 acres
Impact on wildlife	Changes in riparian habitat
Impact on people (amenities and aesthetics)	Loss of farms and villages by impoundment of water. Loss of recreation associated with free-flowing river
Impact on aquatic environment	Impoundment of water forms deep pools which causes physical, chemical, and biological changes and a biologically impoverished zone caused by fluctuations of reservoir water level; alternating downstream habitats; modifying patterns of fish migration and possibly terrestrial animal migration; and imposing stress and mortality on fish and wildlife
Nuclear power fraction	
Hypothetical quantity generated	About 1050 MWe
Amount of land preempted	1500 to 2000 acres, 250 acres of which is permanently disturbed
Impact on wildlife	Minor loss of animal wildlife habitat. Some chemical destruction of plant life from drift of salts and biocides in cooling tower plume
Impact on people	Minor loss of cropland. Radiation dose to population not more than 2% of natural-background radiation dose
Impact on aquatic environment	Annual consumption of 5000 acre-ft of water if plant uses closed-cycle cooling

Table 10.1 (continued)

Population or resource affected	Description
Coal-fired power fraction	
Hypothetical quantity generated	About 1200 MWe
Amount of land preempted	35 to 280 acres/year for mining, the magnitude depending on the mining method and the section of the country involved
	400 acres for the power plant
Impact on wildlife	Loss of habitat. Destruction of habitat from acid mine drainage to water supplies and food sources
Impact on people	Contamination of surface-water and groundwater supplies and arable lands from acid mine drainage. Erosion of land. High occupational hazards in mining
	Accidental fatalities in mining and coal transportation to the power plant
	Exposure of the population to airborne power-plant discharges of pollutants with such adverse health effects as respiratory diseases, lung cancer, physiological irritation, and direct toxicity possible, especially if air concentrations are high
Impact on aquatic environment	Turbidity and contamination of streams from acid mine drainage and erosion, together with destruction of aquatic life in receiving water bodies
	Heavy metals, organic contaminants, and potentially toxic substances in the runoff from coal storage piles and ash ponds passing into receiving waters, resulting in destruction of aquatic life
Combustion turbine fraction	
Hypothetical quantity generated	About 170 MWe
Impacts	Not available (see text)
Pumped storage fraction	
Hypothetical quantity generated	About 100 MWe
Impacts	Not available (see text)
Resource uses	
Gasoline and diesel fuel requirement (1984)	308,000 gal/year
Water consumed	18 Mgd
Coal consumed	40,000 metric tons/year average estimated
Electricity consumed	2080 MW for maximum operation
Uranium used as feed	8929 short tons/year

[a] Chemicals are discharged into both the Clinch River and Poplar Creek. The discharge into Poplar Creek occurs about 4 ½ miles upstream of its confluence with the Clinch. The total combined discharges are discussed in this table in terms of resultant concentrations downstream of the plant.

[b] Radionuclides are discharged to both the Clinch River and to Poplar Creek. The discharge into Poplar Creek occurs about 4 ½ miles above its confluence with the Clinch. The total combined discharges are discussed in this table in terms of resultant concentrations downstream of the plant.

[c] Read as 1.5×10^3.

[d] Read as 3.2×10^{-5}.

Table 10.2. Background chemical concentrations in the Clinch River and concentration increases due to ORGDP liquid discards

	Background concentration[a] (mg/liter)	Increase in Clinch River concentration (mg/liter)
Aluminum	8E–1[c]	1E–5
Arsenic	1E–2	0
Cadmium	<5E–3	0
Cyanide	1E–3	2E–6
Chromium	5E–3	3E–5
Copper	2E–2	1E–5
Iron	7E–1	1E–5
Fluoride	<1E–1	4E–4
Mercury	<9E–4	7E–7
Potassium	3	0
Manganese	4E–2	8E–5
Nickel	9E–3	1E–4
Nitrate	4	5E–3
Phosphorus	7E–2	2E–4
Lead	2E–2	1E–7
Silicon	3	4E–7
Sulfate	38	9E–1
Technetium	N.A.[d]	4E–8
Uranium	N.A.	9E–5
Zinc	3E–2	9E–5
Suspended solids	10	1E–2
Dissolved solids	187	6E–1
Betz Polynodic 562	N.A.	3E–3
Betz 35A	N.A.	7E–4
Polychorinated biphenyls	[e]	[f]

[a]Background chemical concentrations in water were determined from water samples collected from the Clinch River upstream of ORGDP in 1977, except for potassium and phosphorus, which were taken in 1972. Some chemical contaminations of river and Poplar Creek sediment have also been detected.

[b]Increases in chemical concentrations in the Clinch River are based on measured ORGDP discards into both Poplar Creek and the Clinch River.

[c]Read as 8×10^{-1}.

[d]N.A. = not available.

[e]The PCB concentration in Clinch River water is below the level of detection Sediment has been found to contain <0.001 to <0.1 μg/g in the Clinch and an average of 11 μg/g in Poplar Creek.

[f]PCB have not been identified in ORGDP discharges. Those PCB found in area stream sediments have not been used at ORGDP for some time.

Table 10.3. **General population characteristics**

Area and year	Total population	Urban		Rural		Median age (years)
		Number	Percentage	Number	Percentage	
Anderson County						
1940	26,504	2,761	10.4	23,743	89.6	N.A.[a]
1950	59,407	33,921	57.1	25,485	42.9	25.5
1960	60,032	32,067	53.4	26,469	46.6	N.A.
1970	60,300	33,831	56.1	26,469	43.9	29.5
Roane County						
1940	27,795	9,601	34.5	18,194	65.5	N.A.
1950	31,665	13,547	42.5	18,207	57.5	25.0
1960	39,133	14,205	36.3	24,928	63.7	26.3
1970	38,881	20,788	53.3	18,093	46.5	29.6
City of Oak Ridge						
1940	0	N.A.	100	N.A.	0	N.A.
1950	30,229	30,229	100	0	0	N.A.
1960	27,619	27,619	100	0	0	N.A.
1970	28,401	28,401	100	0	0	N.A.

[a] N.A. = not available.

Source: S. W. Brewer et al., *A Study of the Impact of the Federal Government on Roane and Anderson Counties,* May 9, 1975.

Table 10.4. **Anderson County automobile tags sold**

1941	3,265
1944	9,204
1945	10,607
1972 (est.)	50,000

Source: The University of Tennessee, Center for Business and Economic Research, Bureau of Public Administration, *A Study of Payments in-lieu-of Taxes by the Atomic Energy Commission to Anderson and Roane Counties, Tennessee, Under the Special Burdens Provision of Section 168 of the Atomic Energy Act of 1954,* Knoxville, Tenn., June 1973, p. 206.

Ridge, Anderson County, and Roane County school systems receive federal assistance under the provisions of Public Law 81-874. Consequently, it is assumed for the purpose of this study that the added costs of operating the school systems are compensated by the federal payments, although the adequacy of these payments remains a topic of controversy.

The socioeconomic effects on Anderson and Roane counties and the city of Oak Ridge during recent years are described in four studies.[1-4] For the two counties, the complex known as Oak Ridge Operations (ORO) represents the major industrial investment within their boundaries, as well as the principal employer of their residents. The DOE facilities, including ORGDP, are relatively self-contained and require few, if any, services from the local entities. Wage rates at the Oak Ridge federal complex for every classification of occupation are among the highest in the state, closer to national rather than local standards. A comparison with some of the rates paid by other local and regional employers is given in Table 10.5. Procurement by DOE contractors has been subject to state and county taxation since the mid-1960s with the revenues (1) to the state under its sales and use tax and (2) to Roane County under its local sales and use tax. The revenues are shared with the city of Oak Ridge. In addition, the two counties and the city receive the federal assistance generally available to local governments impacted by federal installations.

Table 10.5. Comparative wage rate information for the Oak Ridge area

	Wage ($/hr)			
Job classification	Union Carbide[a]	Oak Ridge schools[b]	Area average[c]	Area average[d]
Machinist	7.54		6.00	5.18
Laborer	5.22		3.87	
Lead carpenter	8.13	6.28		
Truck driver	5.99	4.45		4.49
Locksmith	8.13	5.32		
Janitor	5.65	4.31		3.56
(Shipping/receiving clerk, $/year	12,126		8,822	8,944)
(Clerk-typist, $/year	8,569	7,548)		
(Secretary, $/year	10,524–10,899	9,534	8,471)	
Lab technician	7.34		5.45	

[a] Various sources, including Oak Ridge School District and industry surveys.

[b] Oak Ridge School District, FY 1979 rates.

[c] Industry surveys, 1978, unpublished.

[d] State of Tennessee, Department of Economic and Community Development, *Wages, Salaries, and Fringe Benefits Survey* (covering Anderson, Loudon, Roane, and Cumberland counties).

Source: Stanford Research Institute International, draft report on annual assistance to the original atomic energy communities, Appendix B, p. B-95.

Socioeconomic costs to the counties and the city of Oak Ridge arise from the related consequences of two situations: (1) the ORO immunity from ad valorem taxation by reason of federal ownership and (2) the need by employees and their families for all the public services and facilities normally provided by local governing bodies.

The combination of tax-exempt federal facilities and the expectations of federally related employees for local public services has repeatedly raised the issues of added financial assistance, in-lieu-of-payment taxes, and possible taxation of DOE contractors and activities.

It is charged that the existence of the facilities with large numbers of employees has financially burdened local governments. The tax bases that remain after omission of federal property from the rolls result in high property taxes on private residences, farms, and small businesses in attempts by local governments to meet budgets. The issue of financial assistance has been pursued by the local entities in terms of two statutory authorities available to the DOE: Section 168 of the Atomic Energy Act of 1954, as amended, and the Atomic Energy Community Act of 1955, as amended. Anderson and Roane counties are eligible under both statutes, and the city of Oak Ridge is eligible under the Community Act. An extended discussion of the assistance experience under these statutes is presented in ref. 5.

The SRI study[2] is the latest in a series of studies that has the purposes of reviewing the justification for financial assistance and of establishing an acceptable means of determining a level of financial assistance within the framework of the DOE statutory authorities. This research arose partly from local dissatisfaction with the amounts and uncertainty of the assistance and partly from local and DOE efforts to establish a more effective solution to the problem. There has as yet been no satisfactory resolution of the issue.

In the absence of conclusive evidence to the contrary, this analysis, with respect to ORGDP, has assumed that the assistance made available by federal programs balances the burdens induced by DOE activities. Consequently, socioeconomic costs associated with public services to DOE-related employees and their families and the socioeconomic benefits associated with federal support programs are not considered in this trade-off analysis.

10.2 BENEFITS

Socioeconomic benefits are summarized in Table 10.6 for both the local area (Oak Ridge, the surrounding counties, and the state of Tennessee) and the nation.

Locally, benefits include employment and payroll; the employment opportunities created, and resultant payrolls, in the 23 counties in which ORGDP employees reside; the purchase of goods and services by ORGDP, through which the local economy is given further stimulus; the availability of the ORGDP fire-fighting equipment in the event of a major fire in the city of Oak Ridge; and the participation of cost-plus-fixed-fee (CPFF) contractor-DOE employees in local government and civic organizations.

Nationwide benefits are extensive, encompassing the availability of energy needed by the United States in the form of nuclear power, a reduction in the consumption of combustible-fuel natural resources, a reduction in the U.S. balance-of-trade deficit through income from sales of separative work to foreign countries, and a reduction in crude-oil imports.

Local benefits

Table 10.7 gives ORGDP employment and payroll by county. There were, as of December 31, 1978, 6344 people employed at ORGDP and an annual payroll of $107,865,672. Because of terminations and retirements, these numbers are slightly less than the maximum employment of 6853 for the year and its payroll of $107,974,831.

Table 10.8 gives the working force in Anderson and Roane counties, in which 61% of ORGDP employees currently live, in ten-year increments from 1940 to 1970. The influence of the advent of the Oak Ridge federal complex on local government is evident in a comparison of 1940 and 1950 levels, particularly for Anderson County.

Table 10.9 shows the annual ORGDP employment levels versus CPFF contractor-DOE employment levels in Oak Ridge. Employment at ORGDP is now about 35% of the total employment at the Oak Ridge complex. The percentage may be lower in 1984 when ORGDP employment drops to 4500.

The influence of the ORGDP payroll on the economy of the area has been estimated based on plant employment, payroll, and the county residences of employees. In a county-by-county computation, employment multiplication factors and the product of employment multiplication and payroll adjustment factors were applied to convert the ORGDP employment and payroll to secondary employment and payroll opportunities. These factors, listed in Table 10.10, are intended to account for the fact that employment income gives rise to expenditures that create further employment and an ongoing chain of income-expenditure-income. The calculations indicate that about 6700 employment opportunities and a payroll of $90 million are created in a 23-county area.

Table 10.6. Principal socioeconomic, technological, and environmental benefits of ORGDP

Benefit category	Description/Quantification
Socioeconomic	
Local	
ORGDP capital investment	\$1,278,618,560, as of 1/15/79
Employment (12/31/78)	6344
Annual payroll (12/31/78)	\$107,865,672
Estimated employment opportunities in 23 Tennessee counties created by ORGDP employment	6700, based on 12/31/78 employment
Estimated payroll in 23 Tennessee counties stimulated by ORGDP employment	\$90,000,000, based on 12/31/78 payroll
Local orders for goods and services in support of ORGDP operations (CY 1978)	
Oak Ridge	\$4,000,000
Anderson County, excluding Oak Ridge	\$4,000,000
Availability of plant fire-fighting equipment in civic emergency	Mutual-aid fire-fighting agreement for Oak Ridge installations
Sociopolitical enhancement	Continued participation of employees in local governments and civic organizations
ORGDP sales and use tax payments to the state	\$3,726,985 for FY 1977
ORGDP payments to Roane County on local option sales and use tax	\$299,743 for FY 1977
National	
Nationwide purchases of goods and services in support of ORGDP operations (CY 1978)	\$126,720,925
Total electric power obtained from separative work produced (1984) (nuclear power plant factor = 75%)	64,600 MWe
Reduction of U.S. balance-of-trade deficit (1984)	
Reduction of crude-oil imports (if 60% of the crude oil used domestically is bought from foreign sources at \$15 per barrel)	\$36 billion/year
Income from foreign separative work sales (at \$88.65 per SWU)	\$229,308,000
Reduction in domestic consumption of combustible-fuel natural resources by nuclear power produced from ORGDP separative work (1984) (based on exclusive use of fuel in each case)	
Natural gas	3×10^{12} ft^3/year
Coal at the mine	1.2×10^8 short tons/year
Crude oil	4×10^9 bbl/year
Technological	
	Spin-off of technical information to nationwide and world use
Environmental	
Decreased demand for coal-fired power-generating plants	Reduced SO_2, CO_2, NO_x, and particulate emissions to the environment

Table 10.7. Distribution, by county, of ORGDP employment and payroll, 12/31/78

	Number of employees living in county	ORGDP payroll earned by employees living in county ($ X 10^3)
Anderson	2438	43,211
Blount	116	1,888
Campbell	77	1,197
Claiborne, Fentress, Grainger, Hamblen, Putnam, Scott, Union, Washington, White	23	378
Cumberland	29	475
Jefferson	12	205
Knox	1517	26,244
Loudon	412	6,494
McMinn	22	378
Meigs	11	162
Monroe	47	755
Morgan	157	2,502
Rhea	15	248
Roane	1450	23,461
Sevier	18	270
Total	6344	107,866

Table 10.8. Employment characteristics of the population

	Year	Total work force
Anderson County	1940	8,333
	1950	20,752
	1960	21,049
	1970	20,965
Roane County	1940	9,469
	1950	10,654
	1960	13,850
	1970	15,493

Source: S. W. Brewer et al., *A Study of the Impact of the Federal Government on Roane and Anderson Counties*, May 9, 1975.

Table 10.9. Trends in employment at ORGDP and the entire Oak Ridge complex

	ORGDP	CPFF[a] contractor/DOE
1966	2,521	13,500
1967	2,618	13,872
1968	2,657	14,304
1969	2,772	14,902
1970	2,759	15,136
1971	2,784	15,278
1972	2,934	14,999
1973	3,668	14,095
1974	4,344	15,304
1975	5,000	
1976	6,048	16,780
1977	6,313	18,164
1978	6,344	

[a]CPFF = cost plus fixed fee.
Source: ORGDP files.

Total ORGDP expenses for goods and services in CY 1978 amounted to \$127 million, about 30% of which was spent in Tennessee. Orders placed in Oak Ridge amounted to \$4 million, and those in Anderson County — excluding Oak Ridge — totaled \$4 million.

The ORGDP, along with the Y-12 Plant, the Oak Ridge National Laboratory, and the city of Oak Ridge, is a participant in a mutual-aid fire-fighting agreement whereby its equipment and personnel will help fight fires at the other plants and in the city in emergencies.

Nationwide benefits

About 70% of the goods and services required by ORGDP in CY 1978 were bought from sources outside Tennessee. As noted previously, the purchases totaled \$127 million.

The separative work units (SWU) to be produced and sold by ORGDP in 1984, functioning as an integral member of the U.S. enrichment enterprise, are estimated at 7760 metric tons SWU.[6] The total revenue from this service, at the current price of \$88.65 per SWU, would be \$687,924,000 for fixed commitment contracts, and the revenue from foreign separative work sales would be \$229,308,000. This and other information associated with separative work sales, both domestic and foreign, is given in Table 10.11.

The total electric power capacity generated by nuclear facilities (75% plant factor) fueled with ORGDP-produced separative work amounts to 64,600 MWe. To put this in perspective, this capacity is over twice the amount of installation capacity in the state of New York.

The fossil-fuel uses avoided by the use of nuclear power from ORGDP separative work in 1984 were calculated from the annual requirements for 1000-MWe electric power plants [75% plant factor, 6.57×10^9 kWhr(e)]:[7]

Natural gas	64×10^9 ft^3
Coal (mined)	2.7×10^6 short tons
Crude oil	9.2×10^7 bbl

If it is assumed that instead of nuclear fuel made from ORGDP separative work one of these fossil fuels will be used exclusively, the annual domestic use would be one of the following:

Natural gas	3×10^{12} ft^3
Coal (mined)	120×10^6 short tons
Crude oil	4×10^9 bbl

Table 10.10. County factors used for employment and payroll opportunity calculations

	Employment multiplication factors[a]	Payroll adjustment factors[b]
Anderson	0.75	0.7
Blount	1.19	0.8
Campbell	1.15	0.5
Claiborne	0.71	0.4
Cumberland	1.20	0.5
Fentress	0.66	0.4
Grainger	0.45	0.5
Hamblen	1.19	0.7
Jefferson	0.84	0.6
Knox	1.59	0.8
Loudon	0.93	0.7
McMinn	1.17	0.7
Meigs	0.56	0.5
Morgan	0.75	0.6
Monroe	0.54	0.6
Putnam	1.25	0.6
Rhea	1.07	0.6
Roane	1.08	0.8
Scott	0.85	0.4
Sevier	0.90	0.7
Union	0.68	0.5
Washington	1.59	0.7
White	0.64	0.5

[a]From Robert R. Nathan Associates, Inc., and Resource Planning Associates, *Recreation as an Industry,* prepared for the Appalachian Regional Commission, December 1966. The factor gives the employment opportunity or the fraction of employment opportunity created for one job in an industry servicing a demand exported from the area.

[b]Calculated from the 1969 median family income for each county as given in *A Study of Payments in Lieu of Taxes by the Atomic Energy Commission to Anderson and Roane Counties.* The University of Tennessee, Center for Business and Economic Research, Department of Business Administration, Knoxville, Tenn., June 1973, with $9733 as the equivalent datum median for CPFF contractors/DOE employee family income for the same year. Sample calculation for the Roane County payroll adjustment factor:

1969 Roane County median family income = $7401
1969 CPFF Contractor/DOE employee median family income = $9733
Payroll adjustment factor = 7401/9733 = 0.76 .

Table 10.11. ORGDP separative work sales, 1984

	Domestic	Foreign	Total
Separative work units sold, metric tons	5173	2587	7760
Toll enrichment feed requirement, MTU/year	6453	3226	9679
Revenue from separative work (at $88.65/SWU)	$458,616,000	$229,308,000	$687,924,000
Electric power capacity from nuclear fuel, MWe	43,100	21,500	64,600

10.3 EFFECT OF ORGDP SHUTDOWN

Shutdown of the ORGDP would make it impossible for the government to fulfill its obligations to provide enriched uranium to the nuclear power industry, domestic and/or foreign, and would result in a loss of revenue and a probable crisis in international relations. On the other hand, the environmental costs associated with ORGDP operations (discards and discharges to the environment and the consumption of natural resources) would disappear.

The TVA would have to, temporarily at least, curtail operations at some of its power-generating facilities. This would result in some reductions of gaseous emissions and liquid discards to the environment (an environmental benefit) but would also result in a layoff of employees (a socioeconomic cost).

Furthermore, ORGDP shutdown would incur the following socioeconomic costs.

1. Substantial unemployment and a depressed economy in the areas relying on ORGDP for payroll and purchases.
2. A tremendous burden on the welfare agencies in the same areas.
3. Increased delinquencies in property taxes and a decline in other tax receipts as family purchases are reduced. The decrease in local government revenues when welfare demands increase would create financial difficulties.

The shutdown of ORGDP would create socioeconomic costs of such magnitude that they could not be counterbalanced by the minor environmental benefits achieved.

10.4 TRADE-OFF DISCUSSION

The major costs associated with the operation of the ORGDP are environmental, whereas the major benefits are socioeconomic. In addition, through the enrichment of uranium, nuclear power is enabled to develop, reducing reliance on fossil fuels for electricity generation and also reducing health hazards associated with fossil fuel use.

A critical evaluation of impacts found no threat to human life — no significant intrusion of toxic materials into the human food chain — and no evidence of major harm to local wild animals, birds, plants, or aquatic life. On the other hand, the socioeconomic benefits are considerable: the amount of power made available to serve the nation and the rest of the world, the reduction in the U.S. balance-of-trade deficit through income from separative work sales to foreign governments, the potential reduction of crude-oil imports, the environmental benefits from decreased use of coal for power generation, and the economic benefits to the local economic system because of plant payroll and purchases.

After an analysis of the trade-off between costs and benefits associated with ORGDP, the staff concludes that the net benefits of plant operation greatly exceed the costs.

REFERENCES FOR SECTION 10

1. Kenneth E. Quindry et al., *A Study of Payments in-Lieu-of-Taxes by the Atomic Energy Commission to Anderson and Roane Counties, Tennessee, Under the Special Burdens Provision of Section 168 of the Atomic Energy Act of 1954,* The University of Tennessee, Center for Business and Economic Research, Knoxville, Tenn., June 1973.

2. SRI (Stanford Research Institute) International, *Analysis of Annual Assistance to Communities at Atomic Energy Facilities,* Menlo Park, Calif., December 1978.

3. S. Wallace Brewer et al., *A Study of the Impact of the Federal Government on Roane and Anderson Counties, Tennessee,* prepared by the Joint Tax Study Committee of Roane and Anderson Counties, May 9, 1975.

4. Tax Study Committee, Quarterly Court of Anderson County, *Study of the Financial Impact of the U.S. Atomic Energy Commission on the Anderson County Government,* February 1971.

5. Ref. 2, chaps. I-V and Appendix B.

6. Personal communication, J. A. Hafford, Oak Ridge, Tenn.

7. U.S. Atomic Energy Commission, *Comparative Risk-Cost-Benefit Study of Alternative Sources of Electric Energy,* WASH-1224, Washington, D.C., December 1974, p. 1-7.

11. LIST OF PREPARERS

1. Summary

J. W. Boyle	Environmental Statements Project Energy Division, ORNL

2. Description of Oak Ridge Gaseous Diffusion Plant

M. E. Mitchell	Environmental Management Group ORGDP

3. Alternatives

J. H. Alexander	Safety and Environmental Control Division Oak Ridge Operations, DOE
J. L. Love	Safety and Environmental Control Division Oak Ridge Operations, DOE

4. Characterization of the Affected Environment

4.1 Regional demography

R. C. DeVault	Social Impact Analysis Group Energy Division, ORNL

4.2 Land use

A. M. Solomon	Environmental Impact Program Environmental Sciences Division, ORNL

4.3 Geology

J. R. Gauthier	Energy Systems Planning Division TRW, Inc., Oak Ridge, Tenn.

4.4 Hydrology

J. R. Gauthier	Energy Systems Planning Division TRW, Inc., Oak Ridge, Tenn.
C. E. Gough	Environmental Impact Program Environmental Sciences Division, ORNL

4.5 Meteorology

J. F. Witherspoon, Jr.	Technical Assessment Section Health and Safety Research Division, ORNL

4.6 Ecology

C. E. Gough	Environmental Impact Program Environmental Sciences Division, ORNL
A. M. Cason	Environmental Impact Program Environmental Sciences Division, ORNL
A. M. Solomon	Environmental Impact Program Environmental Sciences Division, ORNL

4.7 Regional landmarks

A. M. Solomon	Environmental Impact Program Environmental Sciences Division, ORNL

4.8 Community characteristics

R. C. DeVault	Social Impact Analysis Group Energy Division, ORNL

5. Environmental Consequences

5.1 Human environment

S. J. Cotter	Technical Assessment Section Health and Safety Research Division, ORNL
R. C. DeVault	Social Impact Analysis Group Energy Division, ORNL
G. S. Hill, Jr.	Technical Assessment Section Health and Safety Research Division, ORNL

5.2 Ecological environment

S. B. Gough	Environmental Impact Program Environmental Sciences Division, ORNL
A. M. Solomon	Environmental Impact Program Environmental Sciences Division, ORNL

5.3 Physical environment

S. B. Gough	Environmental Impact Program Environmental Sciences Division, ORNL
A. M. Solomon	Environmental Impact Program Environmental Sciences Division, ORNL

5.4 Impacts of offsite power production

R. B. Craig	Environmental Impact Program Environmental Sciences Division, ORNL

5.5 Potential accidents

S. J. Cotter	Technical Assessment Section Health and Safety Research Division, ORNL
S. B. Gough	Environmental Impact Program Environmental Sciences Division, ORNL
G. S. Hill, Jr.	Technical Assessment Section Health and Safety Research Division, ORNL
A. M. Solomon	Environmental Impact Program Environmental Sciences Division, ORNL

6. Unavoidable Adverse Environmental Effects

S. B. Gough	Environmental Impact Program Environmental Sciences Division, ORNL

7. Irreversible and Irretrievable Commitments of Resources

J. W. Boyle	Environmental Statements Project Energy Division, ORNL

8. Relationship of Land-Use Plans, Policies, and Controls

J. W. Boyle	Environmental Statement Project Energy Division, ORNL

9. Relationship Between Short-Term Uses of the Environment and the Maintenance and Enhancement of Long-Term Productivity

J. W. Boyle	Environmental Statements Project Energy Division, ORNL

10. Environmental Trade-Off Analysis

R. B. Schappel	Operations Analysis and Planning ORGDP

Appendix A — Geologic Formations of the Oak Ridge, Tennessee, Area

J. R. Gauthier	Energy Systems Planning Division TRW, Inc., Oak Ridge, Tenn.

Appendix B — Environmental Measurement and Monitoring

J. M. Loar	Environmental Impact Program Environmental Sciences Division, ORNL
A. M. Sasson	Environmental Impact Program Environmental Sciences Division, ORNL
A. M. Solomon	Environmental Impact Program Environmental Sciences Division, ORNL

Appendix A*

GEOLOGIC FORMATIONS OF THE OAK RIDGE, TENNESSEE, AREA

*From W. M. McMaster, *Geologic Map of the Oak Ridge Reservation, Tennessee*, ORNL/TM-713, Oak Ridge National Laboratory, Oak Ridge, Tenn., Nov. 22, 1973.

A.1 ROME FORMATION

The Rome Formation is composed of interbedded sandstone, siltstone, shale, and dolomite. The bulk of the formation in the Oak Ridge area is siltstone and shale. Sandstone beds, which range in thickness from 3 to 14 in., are more abundant in the upper half of the formation than in the lower.

The sandstone is composed of light-gray to light-brown, fine- to medium-grained quartz and is cemented with silica or iron oxide. The sand is so well cemented in places that it appears quartzitic. Generally, the weathered surfaces of the sandstone are dark brown or red-brown.

Siltstone in the Rome is generally light to dark brown and green-brown, thin-bedded, and has irregular bedding surfaces with concentrations of small flakes of mica.

A striking characteristic of the Rome is its banded coloration, primarily caused by the shale beds, which are green, maroon, red, violet, purple, yellow, tan, and brown. Very small flakes of mica are common along the bedding surfaces.

A belt of shale occurs northwest of Pine Ridge, which heretofore has not been assigned a definite stratigraphic position. It is faulted above and below, has no obvious lithologic similarity to other formations in the area, and lacks identifiable fossils. The shale is dominantly maroon, red, and tan, fairly silt-free clay, interbedded with lesser amounts of brown, purple, and green, more silty clay. The maroon and red shale beds may be a potential source of brick clay since they are very similar to the shale of the Pennington Formation of Mississippian age which is used in several places in southwestern East Tennessee for brick and pottery. The surface over the shale is characteristically strewn with 2- to 6-in.-diam cobbles of dense blue-white to blue chalcedony, which is probably derived from weathering of calcareous beds interbedded with the shale. Many of these cobbles exhibit cryptozoanlike structures on the exterior. Wad (a hydrous manganese oxide mineral) occurs locally as nodules in the shale, and a few fine- to medium-grained, maroon and brown thin-bedded sandstone beds are present.

The shale is thought to be an older part of the Rome Formation not exposed in the belts southeast of Pine Ridge, perhaps corresponding to the Apison Shale member of the Rome, which crops out in southwestern East Tennessee. For the purpose of differentiation from the Rome underlying Haw Ridge, the shale unit is designated by the symbol Crs in Fig. 4.2.

The typical sandstones and siltstones of the Rome are characterized by abundant primary features such as ripple marks, rill marks, swash marks, mud cracks, and, locally, raindrop imprints.

The lower contact of the Rome is not exposed in the Oak Ridge area; it is always in fault relationship with younger rocks that lie underneath it. The upper contact with shale of the Conasauga Group is gradational and was chosen arbitrarily, based primarily on topography and the coloration of the shales (the shales of the Conasauga are not as brightly colored as those of the Rome Formation).

The Rome Formation underlies ridges that are typically narrow, steep-sided, and broken by many closely spaced wind and water gaps which give the ridges a "comby" appearance.

The residual soil of the Rome is generally less than 15 ft thick and is composed of sandy, silty, light-colored clay containing scattered siltstone and sandstone fragments.

No fossils were found in the Rome of the Oak Ridge area, but those found in the formation elsewhere show that its age is youngest Early Cambrian. The total thickness of the formation is not present in the Oak Ridge area, but probably 800 to 1000 ft of the upper part of the Rome is represented. The thickness of the older part of the Rome has not been determined.

A.2 CONASAUGA GROUP

The Conasauga is primarily calcareous shale interlayered with limestone and siltstone.

The shale of the Conasauga ranges from pure clay shale to silty shale and is brown, tan, buff, olive green, green, and dull purple. Dark-gray, dense to crystalline, nodular, thin-bedded, silty limestone is interbedded with the shale and siltstone in the lower two-thirds of the group. Siltstone, which is brown, red-brown, buff, and tan, is present throughout the lower four-fifths of the group and is abundant in the layers underlying a line of knoblike hills on the northwestern sides of the valleys underlain by the Conasauga.

Alternating beds of shale and light-gray, dense to crystalline, regularly bedded limestone are present about 500 ft below the top of the group. These beds are overlain by about 300 ft of massive, light- to medium-gray, dense to coarsely crystalline or oolitic limestone. The upper limestone beds of the Conasauga are used in many places in East Tennessee as a source of quarry stone for road aggregate; most of this limestone is fairly pure, and the oolitic beds are composed of nearly pure calcium carbonate.

The contact between the limestone of the Conasauga Group and the dolomite of the Knox Group is gradational from dolomitic limestone to dolomite containing stringers of limestone.

The Conasauga Group underlies valleys between ridges formed by the Rome Formation and the Knox Group. The surfaces of these valleys are characteristically irregular, with many gullies and small hills. The most prominent topographic feature is the line of knobs on the northwestern sides of the valleys.

Residuum derived from shale in the Conasauga is generally thin. Weathering has penetrated to a depth of about 20 ft in the layers where shale predominates, but the weathered part retains the appearance of the original rock, except that most of the limestone has been removed. The residuum derived from the massive limestone is characteristically orange-red and contains little or no chert.

The thickness of the Canasauga Group is difficult to measure due to a number of minor folds and faults, but it is estimated to be 1500 ft or more. The age of the Conasauga is Middle and Late Cambrian.

A.3 KNOX GROUP

The Knox is composed primarily of massive, siliceous dolomite. The group can be divided into five formations on the basis of lithologic variations, but it is shown undivided in Fig. 4.2.

The general variation in lithology is from massive, dark-gray, crystalline, very cherty dolomite at the base to generally less massively bedded, lighter gray, dense to finely crystalline, less cherty dolomite on the top. Thin beds of light-gray, dense limestone are present in the upper part, and thin beds of relatively pure sandstone occur about 1000 ft above the base of the group. Outcrops of the dolomite are not abundant due to the rapid weathering and deep soil cover; however, on the northwestern sides of ridges underlain by the group, erosion has removed the soil cover to an extent that outcrops are fairly common.

The amount and type of chert left by weathering varies from formation to formation within the group; and, because outcrops of the dolomite are not abundant, residual chert is used as a basis for differentiating the group. Due to the varying amounts of chert retained in the residuum, the rate of erosion varies from formation to formation, producing a distinctive topography which is an aid in mapping.

The upper contact of the Knox Group is disconformable; that is, it is a surface once exposed to erosion, then covered by sediments, with no significant variation between the dip and strike of the layers beneath the erosional surface and those above. The relief on this surface is rather high in some places, as indicated by the irregular contact line on the map where it is well defined for some distance (Fig. 4.2). The Knox Group-Chickamauga Limestone contact is usually distinct because of the sharp contrast between the dolomite and the overlying basal beds of the Chickamauga; also, springs are common along or near the contact, especially in East Fork Valley.

The Knox weathers to form a deep residual mantle held in place by the abundant chert on the surface. The surface of the bedrock beneath the soil mantle is very irregular; outcrops generally represent the tops of pinnacles of bedrock projecting through the soil.

The Knox Group underlies broad ridges generally having fairly gentle slopes on the southeastern side and steeper slopes on the northwestern side. Variation in resistance to erosion leads to the development of a saddle shape in profile when viewed parallel to strike.

The dolomite of the Knox is very soluble and caverns are common, some of which are large. Sinkholes are a persistent topographic feature of the group.

Fossils are not common in the Knox Group, but small coiled gastropods were found in a limestone bed in the upper part of the group on the northern side of McKinney Ridge. The age of the Knox is Late Cambrian and Early Ordovician. The total thickness is about 3000 ft.

A.4 CHICKAMAUGA LIMESTONE

The Chickamauga Limestone underlies Bethel Valley, East Fork Valley, and a narrow belt northwest of Pine Ridge.

Lithologically, the Chickamauga is extremely variable, although the entire sequence is calcareous. In the two major valleys underlain by the formation, East Fork Valley, where a complete section is present, and Bethel Valley, where the upper 500 ft or more have been faulted out, the stratigraphic succession of beds within the formation is dissimilar.

In East Fork Valley, the lowermost beds of the Chickamauga are composed of discontinuous thin layers of bentonite material; gray clay shale with obscure bedding; thin-bedded, maroon, calcareous siltstone up to 50 ft thick; and gray, calcareous, micaceous siltstone. The lateral continuity of these basal beds is irregular, and, in places, this sequence is absent. Locally, the basal layers contain fragments of chert derived from the underlying Knox Group. A sequence of limestone about 1500 ft thick lies above these layers. The limestone is dominantly light to medium gray and blue gray, dense to finely crystalline, shaly, and thin-bedded, and contains variable amounts of chert. These layers usually contain fragmentary, small-fossil brachiopods, bryozoans, corals, and crinoid stems. The character of these beds changes along strike and similar lithologies recur in various zones, making division into units difficult. Near the top of this limestone sequence are two bentonite beds which lie about 50 ft apart stratigraphically. Above the upper bentonite is a 40-ft sequence of yellow and maroon, calcareous siltstone beds, at the top of which is an apparently small disconformity. Blue-gray limestone, which is coarsely crystalline, extremely fossiliferous, relatively pure, and more massively bedded than the underlying limestones, lies above the disconformity. Unlike the layers of shaly limestone below, this lithology is relatively homogeneous along strike.

The coarsely crystalline limestone grades upward into the Reedsville Shale, a calcareous, tan to orange-brown, fissile, thin-bedded, fossiliferous shale, which is the uppermost unit of the Chickamauga Limestone. This unit is 200 to 250 ft thick.

In Bethel Valley, lithologic differences within the formation are more distinct, and the stratigraphic sequence is more easily defined than in other parts of the area. The residual mantle is generally thinner and outcrops of the beds are more common than in East Fork Valley. Also, the beds are persistent in character along strike and each unit has more distinguishing features. The Chickamauga in Bethel Valley can be divided into at least eight units.[1] Three of these units consist of redbeds: one about 120 ft above the base, another near the middle of the formation, and another at or near the top. These redbeds apparently are not represented in East Fork Valley, although the thin, discontinuous redbeds at the base of the formation in this belt may correspond to the lower redbeds of Bethel Valley. No bentonites have been observed in Bethel Valley; apparently, the Copper Creek Fault displaced beds somewhat below the bentonites.

In other respects, the beds of gray, shaly limestone in Bethel Valley are similar to those of East Fork Valley in color, bedding characteristics, and chert and fossil content.

In East Fork Valley, the Chickamauga Limestone-Sequatchie Formation contact is placed below the lowest occurrence of maroon, calcareous siltstone. Generally, the contact is covered by residuum and, in most areas, has to be approximated.

The soil produced by weathering of the Chickamauga typically consists of yellow, light red-orange, or red clay containing variable amounts of chert. Chert is abundant enough in the lower layers to cause development of a line of low hills on the northwestern sides of the valleys. This is more pronounced in Bethel Valley, where the basal material is composed of alternating siltstone beds and beds of blocky chert.

The surfaces of the valleys underlain by the formation are irregular; the more silty and cherty layers underlie low ridges and hills. Sinkholes are present, but these are not as numerous or as large as those in the Knox Group.

Fossils, including brachiopods, bryozoans, gastropods, cephalopods, crinoid stems, corals, and trilobites, are common throughout the formation.

The age of the Chickamauga Limestone is Middle and Upper Ordovician. The boundary between Middle and Upper Ordovician rocks in this area is drawn at the base of the Reedsville Shale. The thickness of the Chickamauga in East Fork Valley is about 2400 ft; in Bethel Valley, about 1750 ft.

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Appendix B

ENVIRONMENTAL MEASUREMENT AND MONITORING

B.1 AQUATIC

During the Oak Ridge Gaseous Diffusion Plant (ORGDP) survey,[1] five major aquatic biological communities (phytoplankton, periphyton, zooplankton, benthic macroinvertebrates, and fish) were sampled from April 14, 1977, to March 31, 1978, at three Clinch River and three Poplar Creek sites. The method and frequency of sampling were determined by the type of community and the dynamics of the species within it. For example, phytoplankton, which exhibit rapid turnover rates during the warmer periods of the year, were sampled at approximately two-week intervals from spring through early fall and at approximately four-week intervals during the winter.

Table B.1 is a summary of the ORGDP aquatic sampling program from which the data presented in Sect. 4.6.2 were obtained. In selecting appropriate field sampling methodologies and laboratory and analytical procedures, consideration was given to those techniques that had previously provided reliable information on qualitative (e.g., species composition) and quantitative (e.g., population density) parameters.[2-5] Details of field collection and laboratory methods and analytical procedures are given in ref. 1.

Table B.1. Summary of ORGDP aquatic biological sampling program, April 1977 to March 1978

Community type and sampling gear	Sampling frequency	No. of sampling dates	No. of samples collected daily at each station	Total no. of samples (all stations)[a]
Phytoplankton				
2-liter Kemmerer	Biweekly: April–October; March Monthly: December–February	17	2	200
Periphyton				
6 Plexiglas slides on floating racks	Monthly: June; August–November; February; March	7	5[b]	187
Zooplankton				
Clarke-Bumpus with No. 20 mesh (76 μ) net	Monthly: April–March	12	2	142
Benthos				
15 × 15 × 15 cm Ponar dredge	Monthly: April; June; August–October; December; March	7	3	126
Fish				
Electroshocking	Monthly: April; June; July; October; March	5	1	26
Stationary experimental gill nets	Monthly: April; June;[c] July; October; February	5	1	26

[a]Values reflect the actual number of samples collected and analyzed. Where samples were scheduled but not taken due to accidental loss, equipment failure, or fluctuating water conditions, notations have been made on the appropriate tables and/or figures in the text.

[b]Two slides (samples) were used for cell counts; three slides (samples) were used for ash-free dry weight determination.

[c]June collections at the three Poplar Creek stations were actually taken on May 24 and 26; the Clinch River stations were sampled on June 2, 1977.

Analyses for several heavy metals and polychlorinated biphenyls (PCBs) were conducted on tissues of several game-fish species (e.g., largemouth bass, bluegill, white crappie) collected in the spring (April through May) and fall (October through November) of 1977. Measurements also were made of concentrations of trace metals in *Hexagenia limbata* nymphs (burrowing mayfly) found in Clinch River and Poplar Creek sediment. Results of these analyses are presented in Tables 5.17 through 5.22 (Sect. 5.2.2).

The Clinch River sampling sites (see Fig. 4.10) were at CRM 10.5 (station 6), downstream from the K-901-A holding pond; CRM 11.5 (station 5), immediately downstream from the mouth of

Poplar Creek and above the K-901-A holding pond; and at CRM 15.0 (station 4), upstream from the confluence with Poplar Creek and above the ORGDP sanitary-water intake located at CRM 14.4.

The Poplar Creek sampling sites (see Fig. 4.10) were at PCM 0.5 (station 3), a backwater area downstream from the last identified effluent release point of ORGDP; PCM 5.5 (station 2), a station also subject to water-level fluctuations in Watts Bar Reservoir but above the area of potential influence of the ORGDP; and PCM 11.0 (station 1), upstream from the stream's confluence with the East Fork of Poplar Creek (PCM 5.6) and above the influence of Watts Bar Reservoir (Fig. 4.10).

B.2 TERRESTRIAL

B.2.1 Continuing programs

Atmospheric samples for fluoride analysis are collected weekly at six sites (F-1 to F-6, Fig. B.1). Fluoride deposition on potassium carbonate-treated paper is analyzed by specific ion electrode methods.[6] Suspended particulates are measured daily with high-volume vacuum samplers at four sites (SP-1 to SP-4, Fig. B.1).

Pine needles and grasses are collected semiannually at 17 stations (VS-1 to VS-17, Fig. B.1) for fluoride analysis by colorimetric methods. Animals and animal tissues are not routinely sampled for nonradiological analysis. Further information and the resulting data from continuing monitoring programs is available in ref. 6.

B.2.2 Preassessment programs

Biological sampling of vegetation and small rodents for fluoride content, fluoride damage, and nickel content is described in Sect. 2.1. Studies on vegetation and soil content of chromium and zinc ions from cooling-tower drift have been published.[7]

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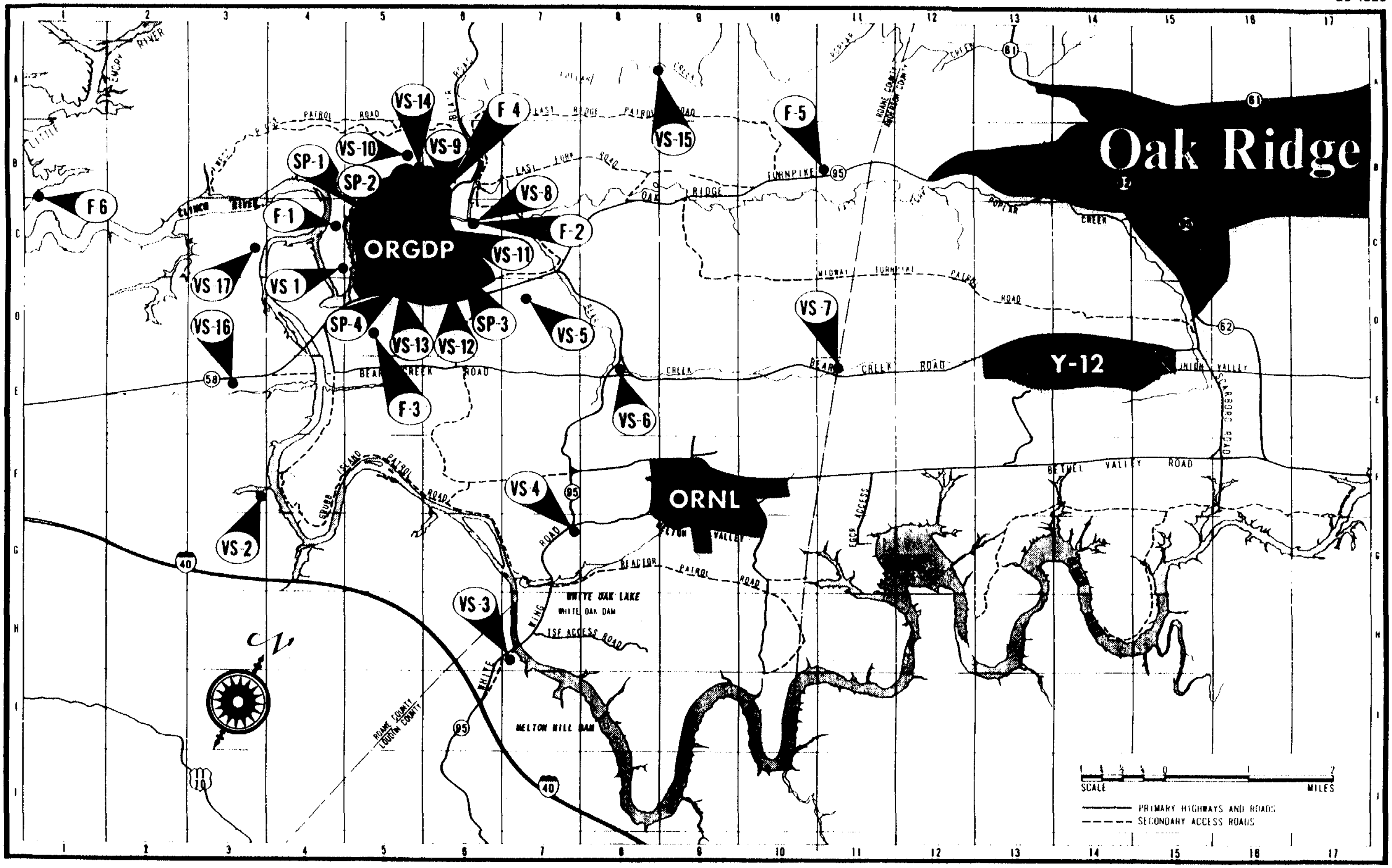

Fig. B.1. Atmospheric monitoring sites for ORGDP.

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